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**From:** Randal English

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**Date:** May 28, 2020

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**Subject:** Yearly Operations Summary – 2019 Beal Year 12 RO Treatment Season

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**Contract:** GS-00F-168CA (Order 12034319F0152)

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Tetra Tech is pleased to submit this Yearly Operations Summary – 2019 Reverse Osmosis (RO) Year 12 Water Treatment Season for the Beal Mountain Mine located 16 miles west southwest of Butte, Montana, in Silver Bow County. This yearly report is required as a deliverable for Task 6 of the Beal Mountain Mine Year 12 Work Order. Data reported includes water volumes treated through the RO Treatment System, heap leach solution level monitoring, and heap leach laboratory and field solution chemistry analytical results.

### **TOTAL LEACH PAD SOLUTION VOLUME TREATED BY RO**

The Beal RO Water Treatment system activities began May 3, 2019 with the restoration of power to the site following snow removal. On May 14<sup>th</sup> Tetra Tech mobilized to the site and began assembling the RO plant and began circulating from the extraction sump (Sump-1) to the reject sump (Sump-3A) in order to clean any accumulated scale from the pipes and begin blending the stratified (presumably) leach pad solution. Full mobilization efforts began on May 17, 2019, with the mobilization of membranes to the site and subsequent plant assembly. The RO system was started on May 30, 2019, and full-scale water treatment began on May 31<sup>st</sup> following minor system repairs. Minor system repairs included pressure gauge checks, pressure transducer calibration, meter calibration, and addressing a non-functioning transducer on the Fresh Water Storage Tank.

At startup, the water treatment totalizer meter reading was reset to zero (0) gallons. The Year 12 contract called for the RO System to produce 18 million gallons of treated water. A contract modification (Mod #1 dated August 28, 2019) authorized the production of an additional 4 million gallons of treated water. The treatment season ended October 14, 2019, with the plant 2<sup>nd</sup> pass permeate (treated water) meter reading 22,006,682 gallons. This is the actual treatment volume for the Year 12 water treatment season. Total treated water produced to date is 234,932,106 gallons.

Heap leach solution elevation in Sump 1 was measured on May 9<sup>th</sup>, 2019 at 7491.45 feet; the solution elevation at the end of the treatment season on October 14<sup>th</sup>, 2019 was 7,482.26 feet.

### **BEAL RO SYSTEM OPERATIONS**

The multi-stage, semi-permeable membranes are the primary contaminant removal component of the Beal Mountain RO system. A membrane functions when influent water is supplied to the membrane surface at a pressure greater than the osmotic pressure of the solution being treated. This creates a significant pressure differential across the membrane, forcing water molecules through the membrane. The pore size on the membranes restrict the passage of impurities, bacterium, and ions larger in size than the pores of the membrane. The solution that passes the membranes is called “permeate”, the remaining solution is referred to as “reject”.

The concentration of contaminants in the solution being treated dictates the operating pressure on the membranes. A higher contaminant load requires higher operating pressure due to the higher osmotic pressure exerted by the water and the dissolved solutes. When operating at elevated pressures, the system must be closely monitored to avoid damaging the membranes. Damage can occur when excessive pressure is applied to the membranes and the differential pressure between the feed side and the permeate side becomes too high, so that ions are forced into the membrane pores or the reject water becomes so highly concentrated that it can no longer keep the ions and molecules suspended in solution resulting in precipitate formation. This precipitation forms solid molecules and is often referred to as membrane “scaling” or “fouling”. Significant scaling greatly reduces the operational capacity of a membrane element, as well as the overall life cycle of a membrane. Meticulous attention must be paid to operational parameters and diligent system adjustments must be made to prevent catastrophic scaling from occurring when operating RO systems near the upper limits of their design capacities, such as the scenario at the Beal RO plant. To operate at the upper limits of design, the amount of permeate needs to be reduced in order to keep solution concentrations in the reject below the point of mass precipitation.

Regular membrane cleaning regiments can be employed to remove minor amounts of scale and fouling. One of the membrane cleaning options include “soaking” the RO membranes (1<sup>st</sup> Pass, 2<sup>nd</sup> Pass, or Both) in 2<sup>nd</sup> pass permeate water (treated water). This process involves pumping stored 2<sup>nd</sup> pass permeate water into the membrane vessels while monitoring the Specific Conductance (SC) of the reject water. Permeate water is pumped into the vessels until the SC measurements of the reject water from those vessels are observed to be at or near the SC values of the water being pumped in. The membrane elements are then allowed to soak in the clean water for approximately 18 to 24 hours. This allows salts and other dissolvable constituents, along with micro fine particulates, to be removed from the membrane surfaces and pore spaces, improving membrane efficiency and reducing the probability of a mass scaling event to occur. The practice of “soaking” the membranes is widely accepted amongst water treatment professionals and is highly recommended by Tetra Tech’s RO experts who are familiar with the current RO configuration and have evaluated the chemical constituents of the Beal RO raw water. Another membrane cleaning option utilizes specially formulated chemicals of low pH (2 – 3) and high pH (10 - 11) mixed in solution. The solutions are then pumped and recirculated through each array of the system at a targeted flow and pressure which allows the solution to scour out precipitates and fouling. Both cleaning regiments were employed during the 2019 water treatment season and are further discussed under section Membrane Cleaning below.

## **Beal RO System Operational Efficiencies**

The volume of treated water was monitored and recorded using the Beal RO system computer software data logger. Tetra Tech has calculated an estimated net effective efficiency for the 2019 RO operations by extracting flow data from the RO influent and 2<sup>nd</sup> pass permeate lines (total gallons solution in and total gallons 2<sup>nd</sup> pass permeate out). The data set consisted of extracting flow meter readings (gpm), at sixty-minute intervals, from archived computer data. The entire 2019 treatment season’s influent and 2<sup>nd</sup> pass permeate flow data was then averaged and divided to produce a single estimate of the efficiency at which the RO treats heap leach pad water. In 2019, it is estimated that for every gallon of water entering the RO system, 0.47 gallons of water was produced as 2<sup>nd</sup> pass permeate, as compared to 0.44 gallons in 2018 and 0.39 gallons in 2017. The values calculated are to be considered as estimates because this method does not account for situations where influent water is not fully processed to produce permeate such as while backwashing the Multi Media Filters (MMF’s) or during startup cycles prior to the system coming fully online. The treatment volumes for years 2008 – 2019 are summarized below in **Table 1**.

**Table 1. 2019 Yearly RO Total Treated Water (2nd pass permeate) Summary**

Year	<sup>1</sup> Total Days	Total Gallons Treated (2 <sup>nd</sup> pass permeate)	Average Treatment Rate (gpd 2 <sup>nd</sup> pass permeate)	<sup>2</sup> Approximate Net Effective Efficiency (%)
2008	61	12,007,550	196,845	45%
2009*	119	25,377,606	213,257	46%
2010	130	33,638,532	258,758	44%
2011	147	32,136,432	218,615	46%
2012*	119	24,959,896	209,747	48%
2013	79	13,881,032	175,709	46%
2014	86	14,712,416	171,075	46%
2015*	64	11,295,392	176,491	45%
2016	73	13,188,800	180,668	44%
2017	84	13,500,660	160,722	39%
2018	110	18,227,100	165,701	45%
2019*	98	22,006,682	224,558	47%

\* Indicates year where membranes were replaced. (24 in 2009; 87 in 2012; 27 in 2015; 35 in 2019)

<sup>1</sup> Days of operation were estimated utilizing archive data from RO computer. Total excludes scheduled maintenance including RO membrane soaking periods.

<sup>2</sup> Based on archive data from Beal RO computer. Data is considered estimated due to being derived from season-long averages of flow streams.

Average 2<sup>nd</sup> pass permeate production rates increased significantly in 2019 with an average daily production rate of 224,558 gallons 2<sup>nd</sup> pass permeate produced. Historic average daily production rates range from 160,722 gallons per day in 2017 to 258,758 gallons per day in 2010. Average 2<sup>nd</sup> pass permeate rates were calculated by dividing the total 2019 2<sup>nd</sup> pass permeate production by the estimated number of full days the plant was in operation, not counting downtime during MMF backwashes or down time during maintenance activities. These production rates should be considered approximate.

The Beal RO system was originally designed for 66% permeate extraction (maximum) through the first pass of the system. That 1<sup>st</sup> pass permeate (66% of original raw) is then sent to the 2<sup>nd</sup> pass of the system where it was designed to extract 90% permeate (maximum) (90% of the 1<sup>st</sup> pass permeate), resulting in a maximum possible net efficiency of 59.4%. This was based on the data collected during the RO pilot project conducted in 2006. The Beal RO water treatment system is currently being operated with 50 – 60% permeate extraction in first pass followed by 60 – 70% permeate extraction in second pass to keep the system pressures at a safe level, prevent equipment damage, and avoid potential scaling. The primary driver for the reduction in the 2<sup>nd</sup> pass recovery is the reverse flow condition present at the YV125A bypass valve. The purpose for the valve in the originally designed system was to return a portion of the 1<sup>st</sup> pass permeate back into 1<sup>st</sup> pass feed, which reduces influent contaminant concentrations and helps balance feed pressures between 1<sup>st</sup> and 2<sup>nd</sup> pass arrays. Thirteen years of operating the RO system has resulted in higher contaminant concentrations in the leach pad influent. The degrading water quality has reduced the RO system capacity and has resulted in an opposite flow path through the YV125A valve. Raw water is now being pushed through the valve into the 2<sup>nd</sup> pass feed waters which

degrades the 1<sup>st</sup> pass permeate water quality. This results in the Beal RO system being operated between 43% and 51% net efficiency. The data presented in **Table 1** above was derived through collecting “snapshots” (once every sixty minutes) of flow rates and averaging them into a single number; therefore, it is an approximation which does not account for system operational variability.

## Beal RO System Operational Availability

The RO system availability is summarized in **Table 2** and is further described below.

**Table 2. RO Treatment System Availability Summary**

Date	Cause of Shutdown	Duration
06/11/2019	Low Power Quality	~ 0.2 Day
06/22/2019 – 06/24/2019	System shutdown for membrane soak	~ 3 Days
07/06/2019	Low Power Quality	~ 0.75 Day
07/09/2019 – 07/10/2019	Low Power Quality	~ 1 Day
07/13/2019 – 07/14/2019	Low Power Quality – T-storm	~ 1 Day
07/31/2019 – 08/05/2019	Membrane soak and Mid-Season Cleaning	~ 5 Days
08/07/2019	RO Surge Tank Pump Impeller	~ 0.5 Day
08/11/2019 – 08/15/2019	Low Power Quality – lightning strike; multiple communication losses and Programmable Logic Controller (PLC) faults; membrane soak while system down	~ 5 Days
08/19/2019	PLC/Supervisory Control and Data Acquisition (SCADA) Communication issues	~ 0.25 Day
08/20/2019	PLC/SCADA Communication issues	~ 0.25 Day
08/25/2019	PLC/SCADA Communication issues	~ 0.25 Day
08/27/2019 – 09/04/2019	PLC/SCADA Communication issues; membrane soak while system down	~ 8 Days
09/09/2019	PLC/SCADA Communication issues	~ 0.5 Day
09/14/2019 – 09/15/2019	PLC/SCADA Communication issues	~ 1.5 Day
09/17/2019 – 09/18/2019	PLC/SCADA Communication issues	~ 0.75 Day
09/23/2019	Low Power Quality	~ 0.2 Day

09/25/2019 – 10/02/2019	PLC/SCADA Communication issues; membrane soak while system down	~ 7.75 Day
10/09/2019 – 10/10/2019	PLC/SCADA Communication issues and frozen pipes	~ 1.75 Days

During the 2019 treatment season, there were numerous unanticipated shutdowns of the RO system due to power quality issues, PLC communications issues (following lightning strike), and mechanical failures.

#### **1<sup>st</sup> Shutdown – Low Power Quality**

Tetra Tech arrived on-site on June 11<sup>th</sup> following notification from the RO system that the unit was down. It was determined that the system shutdown was caused by a “Low Power Quality” fault likely due to a power bump rather than full loss of power.

#### **2<sup>nd</sup> Shutdown – Operator initiated Shutdown for Membrane Soak**

The RO system was intentionally shut down on June 21<sup>st</sup> for a 48-hour membrane soak. Second pass permeate was pumped through 1<sup>st</sup> pass (both stages) and 2<sup>nd</sup> pass (all 3 stages) utilizing the clean in place (CIP) system at the flow and pressure recommended by the element manufacturer. The system was restarted June 24<sup>th</sup>.

#### **3<sup>rd</sup> Shutdown – Low Power Quality**

Tetra Tech arrived on-site on July 6<sup>th</sup> following notification from the RO system that the unit was down. It was determined that the system shutdown was caused by a “Low Power Quality”, low voltage fault at the RO plant and a well fault on the frequency drive at the well head, which was most likely due to a brief systemwide power loss. The system was restarted on July 6<sup>th</sup>.

#### **4<sup>th</sup> Shutdown – Low Power Quality**

Tetra Tech arrived on-site on July 10<sup>th</sup> following notification from the RO system that the unit was down. It was determined that the system shutdown was caused by a “Low Power Quality”, power failure. The system was restarted on July 10<sup>th</sup>.

#### **5<sup>th</sup> Shutdown – Low Power Quality**

Tetra Tech arrived on-site on July 14<sup>th</sup> following notification from the RO system that the unit was down. It was determined that the system shutdown was caused by a “Low Power Quality” fault likely due to a power bump rather than full loss of power. The sensitivity of the power sensor was slightly reduced, and the system was restarted.

#### **6<sup>th</sup> Shutdown – Operator initiated Shutdown for Membrane Soak and Mid-Season Cleaning**

The RO system was intentionally shut down on July 31<sup>st</sup> for a 24-hour membrane soak prior to the start of the mid-season cleaning. The precleaning soak was utilized to enhance the effectiveness of the cleaning chemical used during the midseason cleaning through removal of dissolvable constituents and micro fine particulates. Upon completion of mid-season cleaning activities, several maintenance items were undertaken including removal and repair of a stainless-steel pipe manifold and the fabrication and installation of the replacement 1<sup>st</sup> pass reject valve. The system was restarted on August 5<sup>th</sup>.

#### **7<sup>th</sup> Shutdown – RO Surge Tank Pump Failure**

Tetra Tech arrived on-site August 7<sup>th</sup> following notification from the RO system that the unit was down due to a “Remote Run Disable” alarm. Tetra Tech personnel began troubleshooting the system to identify the source of the alarm which is generic to any unexpected condition controlled by the desktop SCADA. Final diagnostic of the alarm determined that the RO Freshwater Storage tank (permeate tank) had been filled to the failsafe limit set in the SCADA due to a failure of the pump impeller on the tank discharge pump. The failed pump and motor were

removed from service and a spare unit was retrofitted to temporarily work in its place. Additionally, during the shutdown Tetra Tech personnel initiated a manual flush of the 1<sup>st</sup> pass membranes to ensure the thorough removal of raw and concentrate waters. During the flush cycle, a 2-inch fitting failed on the flush pump and began spraying water throughout the front portion of the RO building. The flush cycle was immediately terminated, and the failed piping was repaired. The manual flush cycle was reinitiated and completed without incident.

### **8<sup>th</sup> Shutdown – Lightning Strike**

On August 11<sup>th</sup>, following severe thunderstorm activity in the area, Tetra Tech personnel checked the operational status of the RO system by remote login to the SCADA system. The system appeared nonoperational and several anomalies were observed on the SCADA computer, however, the system had not initiated the remote notification protocol of automated phone calls. Tetra Tech personnel immediately mobilized to the site and upon inspection, found that the SCADA had identified a low inlet pressure alarm and multiple communication loss faults from various components of the system.

System troubleshooting over the next several days identified burnt circuitry in the Freshwater Storage tank pressure transducer, damaged fuses in both the main PLC cabinet and well head PLC cabinet, fault at the well pump variable frequency drive (VFD) control, fault on the well head flow meter, nonresponsive well head PLC communications module, and burnt circuitry on one of the main PLC input modules at the RO plant. Replacement components were procured, installed, and the system was restarted on August 16<sup>th</sup>.

Tetra Tech personnel continued trouble shooting the system faults and replaced or repaired the observed damaged components as they were identified. The repair work following the lightning damage was extremely challenging due to the complexity of how the component failures manifested. The exact circumstances of the communication stoppages were rarely repeatable and generally were random. Following a repair, the system would often operate for a period of time (varying from hours to days) without incident but then would unexpectedly fault again. With each repair, it appeared the issues had been resolved, only to have a fault or communications failure cause the RO unit to shut down again. The work that Industrial Systems was conducting over the internet required Tetra Tech personnel to physically be onsite to monitor the system and perform physical tasks and testing needed to troubleshoot the system and complete the repair work.

### **Multiple Shutdowns – PLC/SCADA Communication Failure**

During the period of August 19<sup>th</sup> through October 10<sup>th</sup> the system experienced numerous unscheduled shutdowns. Table 2, above, provides a synopsis for the frequency and approximate duration of system shutdowns and failures which continued to plague the Beal RO PLC and SCADA network following the August 11<sup>th</sup> event.

Shutdown durations ranged from a few hours up to 8 days. With the exception of a short duration shutdown on September 23<sup>rd</sup> due to a power quality issue, all shutdowns during this period were associated with ongoing electronic system communication issues as a result of the lightning strike on August 11<sup>th</sup>. During this period, Tetra Tech replaced the following components: multiple PLC and input modules in the main PLC cabinet, main PLC rack and power supply, Human Machine Interface (HMI) screen, network router, all network switches, most ethernet cables, added necessary hardware to isolate internal system communications from the internet by routing through a designated fiber optic line. Repair of the system was further complicated by the fact that finding replacement components was found to be especially challenging due to the “age” of the Beal RO unit. At 12-years in operation, the hardware platform of the PLC’s, Human Machine Interface (HMI), and communications systems are no longer manufactured or supported. The replacement components were procured through Industrial Systems and were generally remanufactured or factory certified used stock and were located through various vendors and suppliers. A more detailed progressive analysis is presented in the “Maintenance Tasks Completed During 2019” section of this report.

### Other Minor System Stoppages

Other minor system stoppages occurred during the 2019 treatment season. For example, brief shutdown and restarts needed during PLC programming changes, cartridge filter replacement, or minor maintenance activities. These stoppages did not significantly affect the system operational availability.

It is estimated that the RO system was operationally available 72% of the time during 2019. This rate was calculated based on 137 days of potential full-scale operation (May 31 to October 14) compared with approximately 98 days of actual operation due to the downtimes noted above. Overall, the RO system downtime was minimized due to significant effort by Tetra Tech and its subcontractor (Industrial Systems Inc.).

Historic RO system operational availability has been as follows:

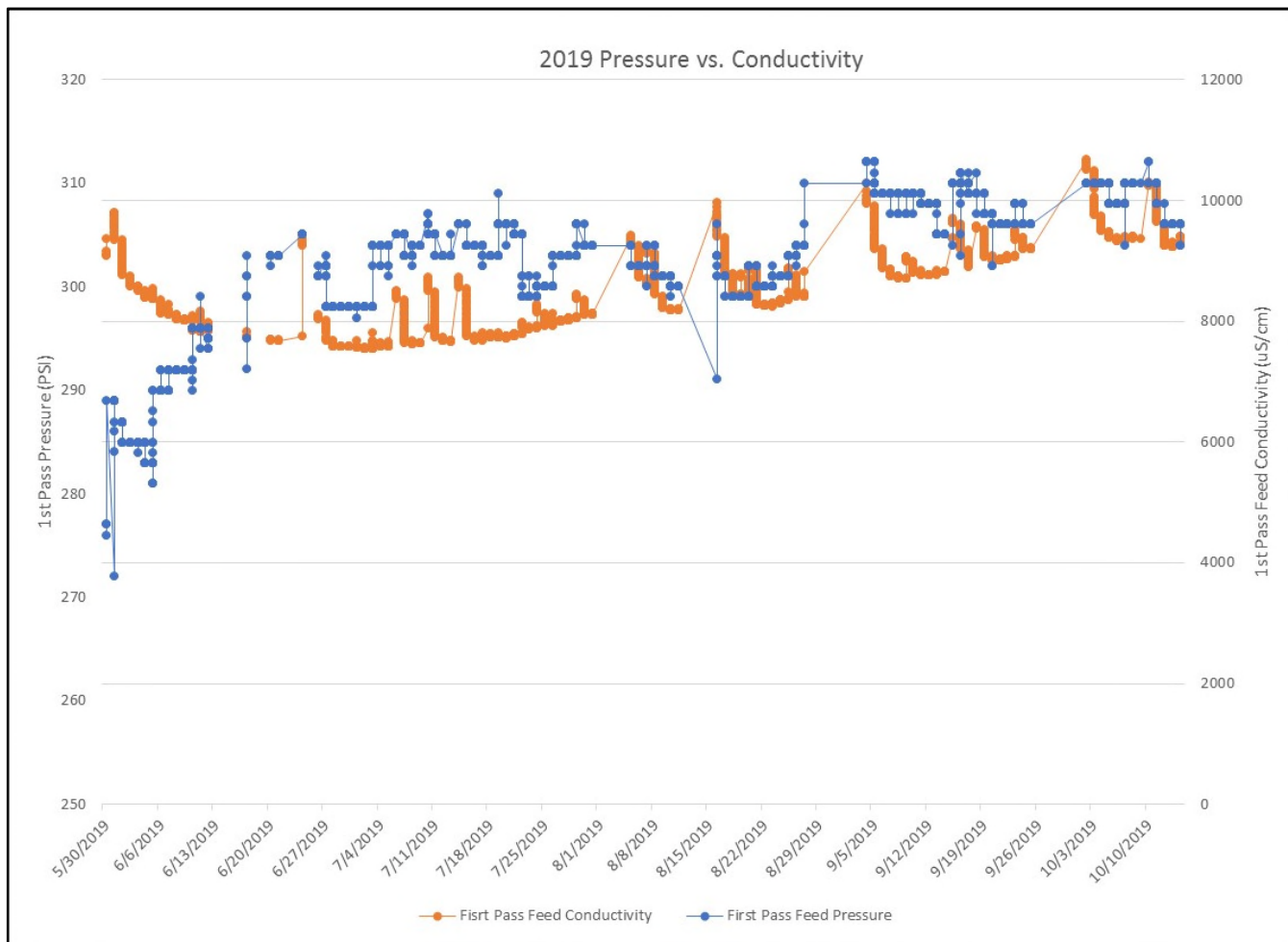
2009 - online 76% of the time  
2010 - online 96% of the time  
2011 - online 97% of the time  
2012 - online 97% of the time  
2013 - online 94% of the time  
2014 - online 91% of the time  
2015 - online 92% of the time  
2016 - online 95% of the time  
2017 – online 95% of the time  
2018 – online 92% of the time  
2019 – online 72% of the time

### BEAL RO SYSTEM WATER QUALITY

#### **General Water Quality**

2019 Beal RO Plant influent water quality was consistent with that observed during previous water treatment seasons. As has been observed in the past, influent water contained elevated Specific Conductance (SC) levels (around 10,000  $\mu\text{S}/\text{cm}$ ) during initial seasonal operation followed by a slow decrease to approximately 7,500  $\mu\text{S}/\text{cm}$  within the first two weeks of operations. During each of the many shutdown periods of 2019, the conductivity would rebound then rapidly decrease upon restart. The longer the shutdown period, the greater the rise in conductivity. This pattern continued throughout the season. A gradual increase in SC was also observed, with an ending value of approximately 9,200  $\mu\text{S}/\text{cm}$  when the plant was shut down on October 14<sup>th</sup>, 2019.

**Figure 1** below illustrates the relationship between 1<sup>st</sup> pass pressures and 1<sup>st</sup> pass (raw water) conductivity where pressure in the 1<sup>st</sup> pass generally increases as water conductivity increases. However, unlike previous treatment seasons where 1<sup>st</sup> pass pressure fluctuations generally coincide with raw water conductivity, pressures at the start of the 2019 treatment season appear lower and increased over subsequent weeks of RO operation, even though the raw water conductivity was initially decreasing. This abnormality was the result of system operational adjustments which were instituted to maximize the 1<sup>st</sup> pass permeate production and minimize the volume of raw water entering the 2<sup>nd</sup> pass feed through the systems balancing line, although these adjustments resulted in higher than normal operating pressures for 1<sup>st</sup> pass (approximately 280 psi in 2018 vs approximately 305 psi in 2019). The elevated flows through the balancing line resulted from the installation of the new second pass membranes which required higher permeate flows (2<sup>nd</sup> pass feed) than the older 1<sup>st</sup> pass membranes could provide. Several smaller spikes in the raw water conductivity can be observed in **Figure 1** which correlate to short term system shutdowns as described in **Table 2** above. Although system adjustments can help alleviate elevated pressures in the RO system, increased raw water conductivity (in general) will cause increases in the RO operating pressures.



**Figure 1 First Pass Pressure Compared with Raw Water Conductivity**

## Laboratory Chemical Analysis

Tetra Tech collected 2 (two) raw influent water samples for analysis according to Table 6 of Tetra Tech's 2012 Reverse Osmosis Water Treatment Plant Sampling and Analysis Plan (WTSAP) (Tetra Tech 2012) during the 2019 treatment season. The first sample was collected during the first week of full-time plant operations (June 6<sup>th</sup>) and the second sample was collected at the end of seasonal RO operations (October 7<sup>th</sup>). Both samples were submitted to Energy Laboratories, Inc. of Helena, Montana, for analysis. Four additional raw influent water samples were collected every other week and submitted for laboratory analysis according to an abbreviated Table 6 of Tetra Tech's 2012 WTSAP. **Table 3** shows the results of the raw influent water samples collected during the 2019 treatment season. Laboratory results are presented in **Appendix A**.

**Table 3. Raw Influent Water Samples**

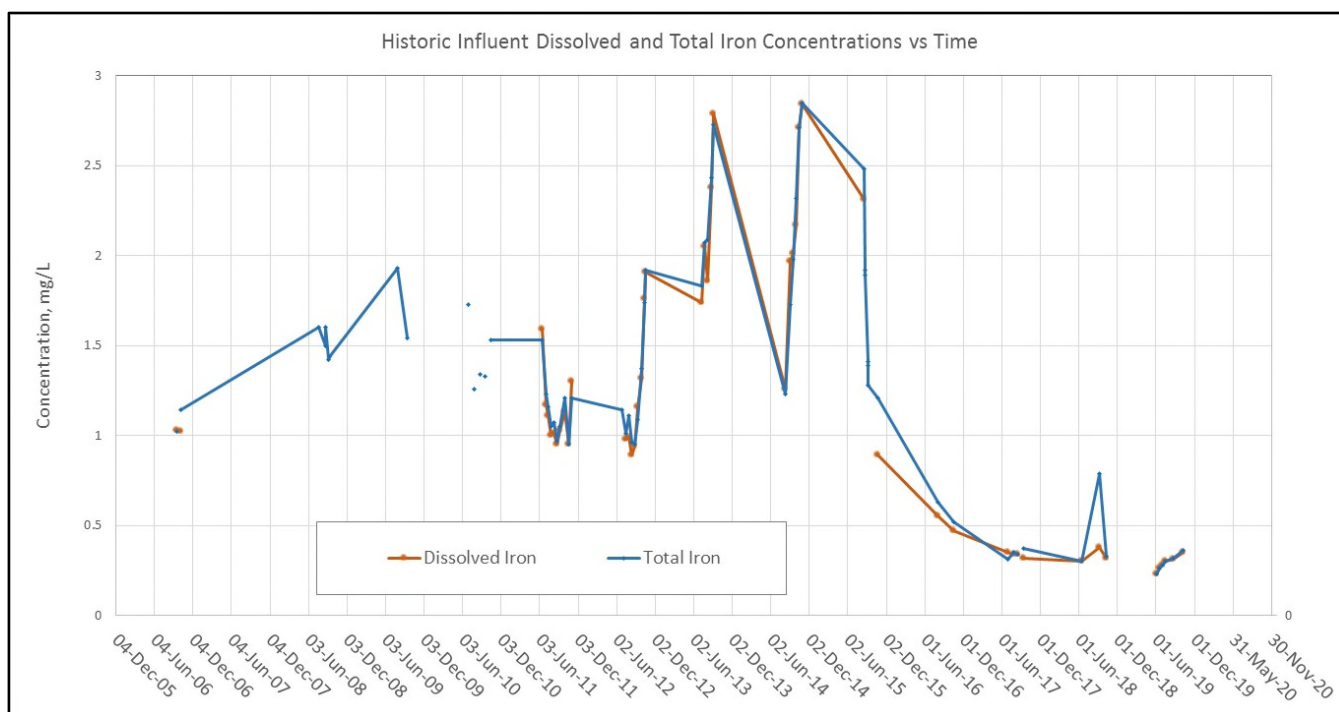
Raw Influent Water Samples	6/6/2019 Start-up	6/20/2019	7/1/2019	7/17/19	8/21/2019	10/7/2019 Shut-down
<b>Physical Properties</b>						
pH (S.U.)	7.7*					7.9*
Total Dissolved Solids (mg/L)	6950	6510	6660	6220	5930	8110
<b>Inorganics (mg/L)</b>						
Thiocyanate as N	4.1					0.69
Alkalinity, Total as CaCO <sub>3</sub>	220	200	210	220	220	210
Chloride	450	447	382	422	472	534
Sulfate	3780	4070	3720	3790	4270	4150
Cyanide, Total	0.5				0.78	0.6
Cyanide, Weak Acid Dissociable	0.004				0.094	0.004
Thiocyanate	1					2.8
Fluoride	0.4	0.4	0.4	0.4	0.3	0.4
<b>Nutrients (mg/L)</b>						
Nitrogen, Ammonia as N	15.3	14.2	14.6	15	17.4	19
Nitrogen Nitrate as N	<0.01	<0.01	<0.01	<0.01	<0.01	
Nitrogen, Nitrate+Nitrite as N	<0.01	<0.01	<0.01	<0.01	<0.01	<0.05
Nitrogen, Nitrite as N	<0.01	<0.01*	<0.01	<0.01	<0.01	0.02
Phosphorus, Total as P	0.08					0.1
<b>Metals, Dissolved (mg/L)</b>						
Calcium	513	510	512	478	497	527
Iron	0.23	0.26	0.28	0.3	0.31	0.35
Magnesium	65	64.2	58.6	56.6	62	74.6
Potassium	20	22	21	21	24	24
Sodium	1510	1510	1460	1510	1660	1820
<b>Metals, Total (mg/L)</b>						
Arsenic	0.197				0.241	0.258
Barium	0.027	0.027	0.026	0.027	0.030	0.035
Cadmium	0.00088				0.0006	0.00090
Copper	0.16				<0.01	<0.01
Iron	0.23	0.26	0.28	0.3	0.32	0.36
Manganese	0.542	0.59	0.59	0.56	0.58	0.62
Selenium	0.023				0.024	0.026
Silicon as SiO <sub>2</sub>	17	18	17.6	17.8	17.7	16.9
Silver	0.0005					<0.0005
Strontium	4.43	4.7	5	4.7	4.9	5.51

\* Analysis performed past recommended hold time

Constituents from the raw water samples were evaluated for concentration changes between the initial sample taken at the beginning of the treatment season and the end of year sample taken prior to system shutdown. Total cyanide increased slightly from 0.5 mg/L to 0.6 mg/L through the season; however, these values were lower than the minimum value observed the 2018 season despite leach pad solution levels being approximately the same. Weak Acid Dissociable (WAD) cyanide also exhibited lower concentrations during the 2019 season ranging from 0.004 mg/L to 0.094 mg/L. Thiocyanate concentrations however, increased over the treatment season from 1 mg/L to 2.8 mg/L, which is similar to values from previous seasons. Alkalinity levels remained stable at approximately 210 mg/L. Chloride level increased from 450 mg/L to 534 mg/L. Total Dissolved Solids (TDS) levels decreased throughout the first half of the season from 6,950 mg/L to 5,930 mg/L then rose sharply to 8,110 mg/L near the end of the season.

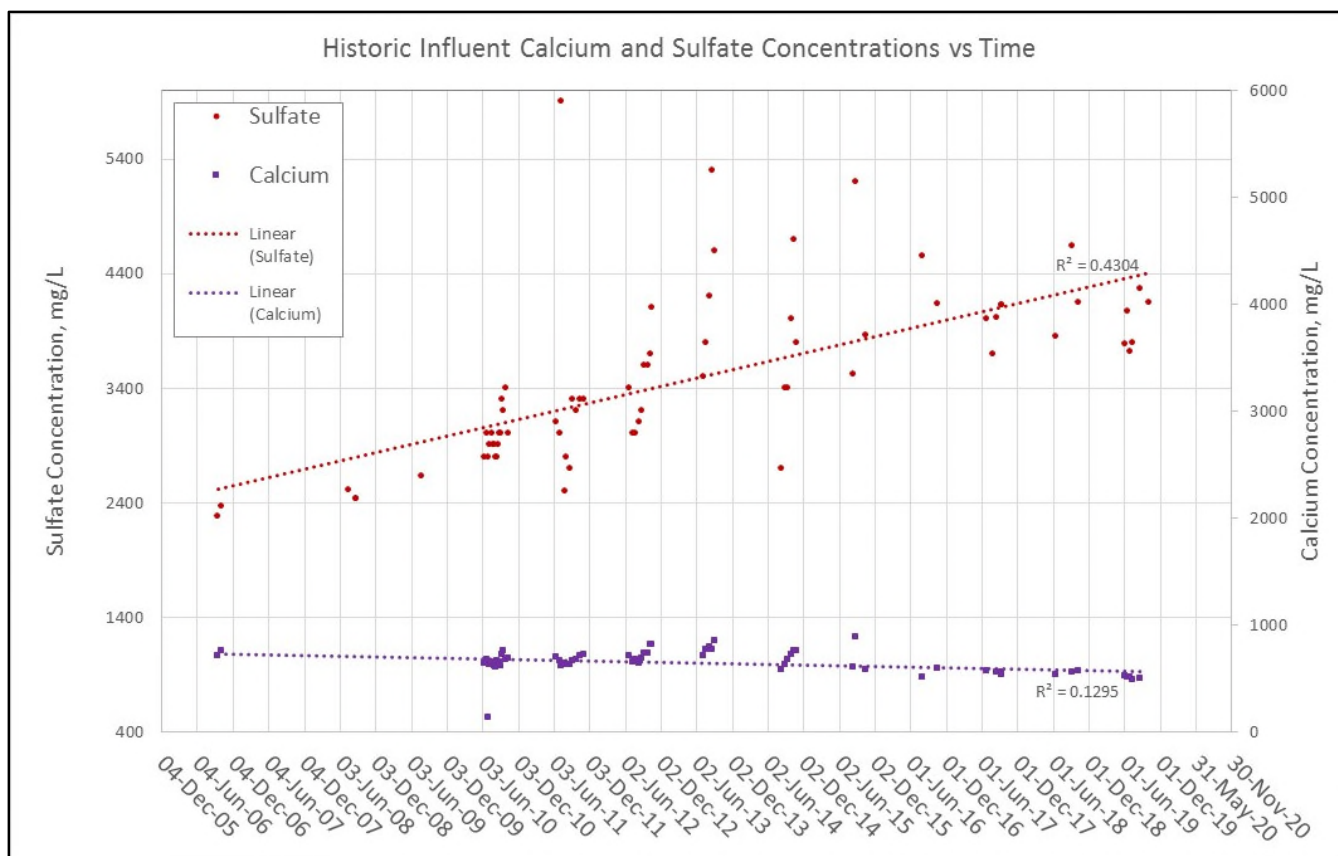
Nutrients remained relatively consistent throughout the treatment season with nitrates and nitrites below the method detection limit of 0.01 mg/L and ammonia ranging from 14.2 mg/L to 19 mg/L.

Dissolved calcium, iron, and magnesium varied slightly throughout the season but generally increased slightly by the end of the treatment season with values ranging from 513 mg/L to 527 mg/L, 0.23 mg/L to 0.35 mg/L and 65 to 64.6 mg/L, respectively. Dissolved sodium increased slightly from 1,510 mg/L to 1,820 mg/L. There were no significant changes in total metals concentrations analyzed over the 2019 treatment season.



**Figure 2. Dissolved and Total Iron Concentrations from 2011 to 2019**

Historic total and dissolved iron concentrations are shown in **Figure 2** above. The data indicates total and dissolved iron concentration values are nearly identical at varying magnitudes of concentration, indicating that most of the iron present in the leach pad is in dissolved form.



**Figure 3. Calcium and Sulfate Concentrations from 2006 to 2019**

Sulfate and Calcium concentrations were also generally consistent with the previous observations. Sulfate varied between 3,720 mg/L and 4,270 mg/L while calcium concentrations varied between 478 mg/L to 527 mg/L. 2018 concentration values for sulfate and calcium in raw water varied between 3,850 mg/L and 4,150 mg/L and 525 mg/L to 569, respectively.

**Figure 3** above illustrates an upward trend in sulfate concentrations of Beal RO raw water since 2006 while calcium concentrations, although with significantly less available data, appears to be trending slightly downward.

Compliance testing for the RO discharge to German Gulch was conducted under the Beal Site Wide Monitoring task. Sampling completed during June was conducted after RO system startup activities but prior to discharge activities and is representative of site conditions without treatment system discharge. During this period, ammonia was below the method detection limit while total cyanide and total recoverable selenium were slightly above their respective chronic aquatic life standards (MDEQ 2019). Selenium and cyanide documented for this period is not associated with treatment system discharge. Additional compliance testing was completed on September 16 during active treatment system discharge as part of Site Wide Monitoring. During this event, all constituents of concern were below chronic-aquatic life standards, and most were below method detection limits.

Laboratory analytic results of all samples collected as part of RO operations during the 2019 treatment season are attached in **Appendix A** and include performance samples associated with cleaning operations.

Results of raw water sampling suggest that leach pad water chemistry did not change significantly over the course of the treatment season.

## Field Tests

Water chemistry tests were performed throughout the 2019 treatment season utilizing field meters and field test kits (Hach®). Samples for field analyses were collected from four locations along the treatment flow path; INF-01 (raw influent water), INF-02 (Post Multi Media Filter (MMF)), 1<sup>st</sup> Stage Permeate (second stage feed), and 2<sup>nd</sup> Stage Permeate (final treated water). The results were recorded and used to analyze the system performance and implement any necessary adjustments to the treatment process. The four monitoring locations are arranged as follows:

- INF -01 (raw influent water) – This monitoring location is used to observe raw influent water pumped from the leach pad prior to being filtered through the MMF's;
- INF-02 (Post MMF) – Monitoring location after MMF's, but before 1<sup>st</sup> stage membrane arrays. Utilized to measure the effectiveness of the MMF's;
- 1<sup>st</sup> Stage Permeate – This monitoring point is on the low-pressure side of the 1<sup>st</sup> stage membrane arrays and before the water enters the 2<sup>nd</sup> stage membrane arrays of the RO system; and
- 2<sup>nd</sup> Stage Permeate – This monitoring point is on the low-pressure side of the final 2<sup>nd</sup> stage membrane array and represents treated water exiting the RO treatment system.

Influent (Raw Water) field conductivity ranged from a minimum of 7,500  $\mu\text{S}/\text{cm}$  on July 1st, after the system had been running for approximately 1 month, to its highest value of 9,330  $\mu\text{S}/\text{cm}$  on October 7<sup>th</sup>, resulting in an overall change of approximately 1,830  $\mu\text{S}/\text{cm}$  as compared to a 3,730  $\mu\text{S}/\text{cm}$  change observed during 2018 and 3,143  $\mu\text{S}/\text{cm}$  change observed during 2017.

2018 field-tested chlorine concentrations remained at or just above the method detection limit. Results of laboratory analysis for chlorine degradation by-products were below the method detection limits. Review of both the field and laboratory results suggests the field test kits may be biased high and that in fact chlorine is not present in the raw influent water at measurable concentrations.

## Membrane Cleaning

Prior to the start of the RO unit, several of the first pass membrane elements (first element of each vessel; 4 vessels per array; A, B, and C arrays in 1<sup>st</sup> pass) required cleaning due to observed debris lodged in the feed ends of the elements. The debris included small particulates of precipitated scale, sand-like particles, and other organic debris which had been observed during removal of the elements in the prior year. Membranes of the "B" and "C" arrays were installed just as they had been in 2018. The four (4) elements located at the feed side of the "A" array were reversed and placed in the back end of the vessels so that any debris dislodged would be removed with the waste stream during normal operations. The A and B arrays were then mechanically isolated by replacing the feed manifold which normally distributes feed waters to both arrays simultaneously (see Photo 1 below) with a single feed manifold (see Photo 2 below) and each array was then flushed with the CIP unit so that any debris dislodged would be captured by the CIP filter system.

### Feed Manifold A and B Arrays



Photo 1. RO A & B Arrays manifold feeding both arrays simultaneously.

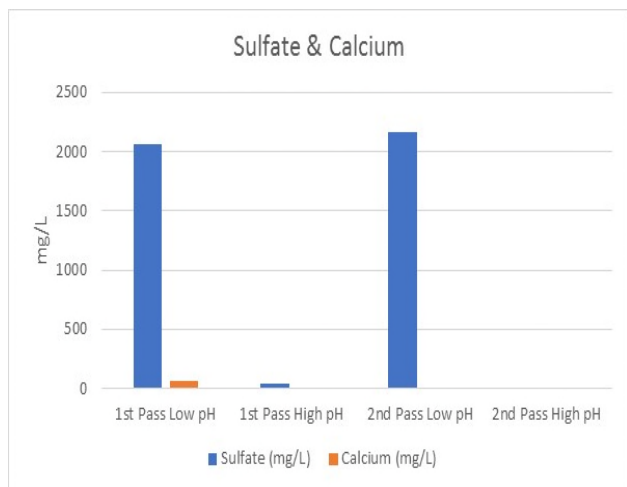


Photo 2. Single manifold placed to feed A or B array independently during cleaning operations.

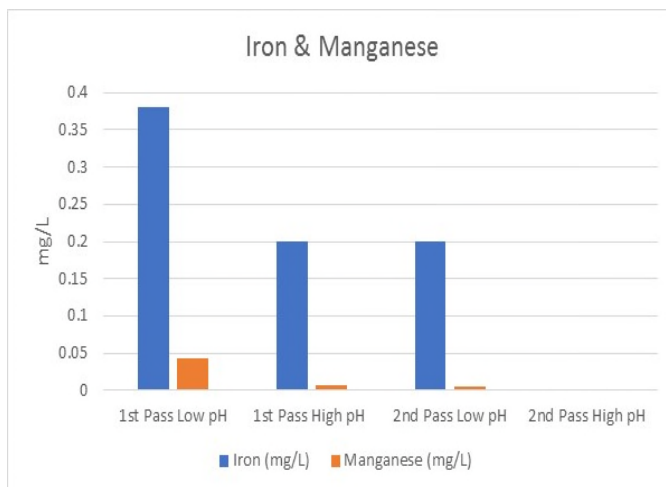
Tetra Tech conducted a mid-season cleaning of the RO membrane elements between July 31<sup>st</sup> and August 5<sup>th</sup>. Cleaning activities were initiated by pumping 2<sup>nd</sup> pass permeate water into each array of the 1<sup>st</sup> and 2<sup>nd</sup> passes of the RO system and allowing the system to soak overnight to loosen particulates and help dissolve precipitates. The CIP skid was then utilized to conduct a two-step chemical cleaning process of low pH solution followed by high pH solution. The first step utilized a cleaning solution of OptiClean™H and RO permeate water. OptiClean™H is a proprietary aggressive low pH, low foaming cleaner formulated to remove metal hydroxides, calcium carbonate, calcium phosphate and other inorganic scale. This product was chosen specifically to combat inorganic fouling that has traditionally been observed on the RO membrane elements and its ability to help reduce gypsum. Cleaning operations included mechanically isolating each array, pumping clean permeate water through each array at a targeted rate of 35-40 gallon per minute per membrane element with a maximum pressure of less than 60 psi. OptiClean™H was then mixed with permeate water in the CIP mixing tank to the concentrations recommended by the manufacture and the solution was recirculated through each array at the targeted rates stated above. Each array was then flushed with clean permeate water until the exiting solution was within 1 pH unit of the raw permeate water. The second cleaning step followed the same process but used a cleaning solution of OptiClean™B. OptiClean™B is a proprietary aggressive high pH, low foaming cleaner formulated to remove organic fouling. After the mid-season cleaning was completed, the system was allowed to soak in clean permeate for 48 hours prior to restarting.

An end of season cleaning of the membranes was performed between October 15<sup>th</sup> and October 18<sup>th</sup>. The cleaning entailed an initial system flush and soak with 2<sup>nd</sup> pass permeate water followed by use of the CIP Cleaning Skid with a low pH cleaner (OptiClean™H) as described above, followed by a thorough rinse with clean permeate water, then a high pH cleaner (OptiClean™B) as described above, followed by a thorough rinse with clean permeate water, and finally, a preserving solution consisting of 1% sodium metabisulfite (by weight) was pumped through the RO elements.

During both the mid-season and end of season cleaning events, samples were collected of the cleaning solution after flushing through the 1<sup>st</sup> pass and 2<sup>nd</sup> pass membranes. **Figure 4** and **Figure 5** below show the concentration of calcium, sulfates, iron and manganese after the cleaning solution was flushed through the membranes. The low pH cleaner seems to be effective at removing calcium and sulfate deposits as well as iron and manganese from the membranes. The high pH cleaner appears to be effective at removing additional iron from the membranes. Laboratory results are presented in Appendix A.



**Figure 4. Calcium and Sulfate Concentration in Cleaning Solution**



**Figure 5. Iron and Manganese Concentrations in Cleaning Solution**

## RO Membrane Maintenance

Tetra Tech conducted two scheduled soak periods as a preventative maintenance measure and three (3) unscheduled opportunistic soak periods during the 2019 operations. The first scheduled soak was completed June 22 through June 24 and the second scheduled soak was July 31 to August 1 just prior to the mid-season cleaning. Three extended soak periods were completed during unscheduled system down time presented in **Table 2** above. These periods included August 11 through August 15, August 27 through September 4, and September 25 through October 2, 2019. Because flow and pressure adjustments to the RO system are required following the soaking periods, improvements to RO membrane performance is difficult to identify when comparing before and after data. However, observations of system fluid conductivity following soaking periods have identified significant increases in SC values. Example: Clean 2<sup>nd</sup> pass RO permeate water (SC≈20 µS/cm) is pumped into the 1<sup>st</sup> pass vessels at low pressure. This process is identified as a “flush cycle” because the water is pushed through the membranes at low pressure not intended to generate permeate, therefore, the water flows through the membranes “flushing” the salts and contaminants from the membrane surface and pore spaces. This “flushing” process continues until the first stage discharge (reject flow) SC concentration is approximately equal to 300 µS/cm or less. The system is then allowed to soak for a minimum of 18 hours, and, upon re-initiation of a flush cycle, the 1<sup>st</sup> pass discharge waters now have SC values approximately equal to 1,500 µS/cm or more, 75-times greater than the water originally pumped into the 1<sup>st</sup> pass vessels.

The Beal RO system was not designed to allow a soaking period for the 2<sup>nd</sup> pass membranes as the quality of the water entering the 2<sup>nd</sup> pass was intended to be clean enough (<300 µS/cm) that soaking periods would not be necessary. However, the Beal RO system was designed with a “bypass valve” (valve YV125A) which was intended to allow minor amounts of raw water into the second pass feed stream if needed (such as system

startup) but generally allow excess 1<sup>st</sup> pass permeate to flow back into the 1<sup>st</sup> pass feed stream. In reality, valve YV125A allows raw untreated water (up to 60+ gpm) to flow into the 2<sup>nd</sup> pass feed stream which greatly increases 2<sup>nd</sup> pass feed constituent concentrations and pressures. The divergence from design is believed to be due to increases in raw water constituent chemistry, degradation of the media in the MMF's, and degradation of the 1<sup>st</sup> pass membrane elements. To combat the possible negative effects of this situation, Tetra Tech personnel pumped permeate water into each array of 2<sup>nd</sup> pass utilizing manual valve overrides during each soak event or periods of extended downtime.

At the end of the 2019 treatment season, the RO membrane elements were cleaned utilizing the CIP system (as discussed above), preserved with a 1% sodium metabisulfite (by weight) solution, and removed from the Beal RO system. Upon removal from the RO unit, each membrane was drained of excess solution, and a year-end inspection consisting of physical examination for signs of scaling or other damage of each membrane was performed. Each membrane was then placed in a new storage bag with both ends heat-sealed closed to protect the membrane element from drying out during storage. The 1% sodium metabisulfite solution is utilized to inhibit microbial growth during long term storage.

## RO Membrane Performance Normalization

Membrane performance in RO operations can be evaluated through a variety of data tracking and calculated parameters. Standard calculated parameters for RO systems in the industry often include differential pressures, net driving pressures, normalized permeate flows, salt passage or rejection, differential pressure drop coefficient, and permeability. Tetra Tech collected a variety of data throughout the 2019 operational season in order to calculate several of the parameters listed above. However, utilizing these parameters for membrane performance for the Beal RO system is difficult to evaluate in detail due to the following:

- Frequent system downtime – Beal RO system downtime, even for short periods of time, results in increased feed solution constituent concentrations (increased SC values) followed by a general downward trend in concentrations as exhibited in the 1<sup>st</sup> Pass Conductivity shown in Figure 1 above. Although these increases in SC are consistent in occurrence, they are not consistent in magnitude, duration, or the subsequent decrease. These observations are consistent with observations from previous years operations and is suspected to be the result of stratification of solution in the Beal leach pad and can result in data volatility.
- Operational adjustments – Operational adjustments to the Beal RO system are routinely performed to maintain appropriate flows and pressures and are often dictated by variations in the feed solution constituent concentrations. Adjustments of the Beal RO system can include feed water flow and pressure for 1<sup>st</sup> and 2<sup>nd</sup> passes, reject solution flow and pressure for 1<sup>st</sup> and 2<sup>nd</sup> passes, and leach pad well solution flow and pressure. Change to flow or pressure at any one of these locations can result in data volatility.
- Equipment calibration – Flow meters, SC meters, and pH meters require frequent checks and calibrations. Most calibration adjustments tend to be minor (less than 1% of display value) but those adjustments can skew data results.
- Variable feed solution constituent concentrations – Feed solution concentration to the RO system varies throughout the season. Decreases, as observed during early season operation, or increases in constituent concentrations due to down time or late season operations, trigger manual system adjustments to maintain appropriate flow and pressures in the system.
- Deteriorated condition of the 1<sup>st</sup> pass concentrate valve and 2<sup>nd</sup> pass feed valve.

Tetra Tech personnel collected specific data during the 2019 operational season to evaluate and optimize RO operations at the Beal Mountain site. The data collected included conductivity and pressure data for both feed and reject stream flows for each individual array of the RO system (1<sup>st</sup> Pass – 1<sup>st</sup> Array, 1<sup>st</sup> Pass – 2<sup>nd</sup> Array, 2<sup>nd</sup> Pass- 1<sup>st</sup> Array, 2<sup>nd</sup> Pass- 2<sup>nd</sup> Array, and 2<sup>nd</sup> Pass- 3<sup>rd</sup> Array). The data collected must then be “normalized” which is a technique used to evaluate if changes in flow or rejection are most likely caused by membrane fouling, membranes degradation, or just due to changes in operating conditions (Lenntech, 2001). The data can help to

determine cleaning regiments, chemical feed rates, and general system adjustments to help reduce the likelihood of creating conditions in the RO system which could lead to mass fouling of the elements.

Overall, the following system performance metrics suggest possible fouling of the 1<sup>st</sup> pass membranes during the early part of the season followed by improved performance latter in the season.

### Net Driving Pressure

The data collected was utilized to calculate Net Driving Pressure (NDP) which is essentially the sum of all forces acting on the membrane. These may include pump or feed pressure; back pressure from line restrictions and storage tank; and osmotic pressure of the feed and permeate waters. The net driving pressure is the measure of the actual driving pressure available to force the water through the membrane. As net driving pressure increases, the flux (permeate production) increases proportionally (given all other factors are held constant).

The average NDP<sub>a</sub> was calculated utilizing the following equation:

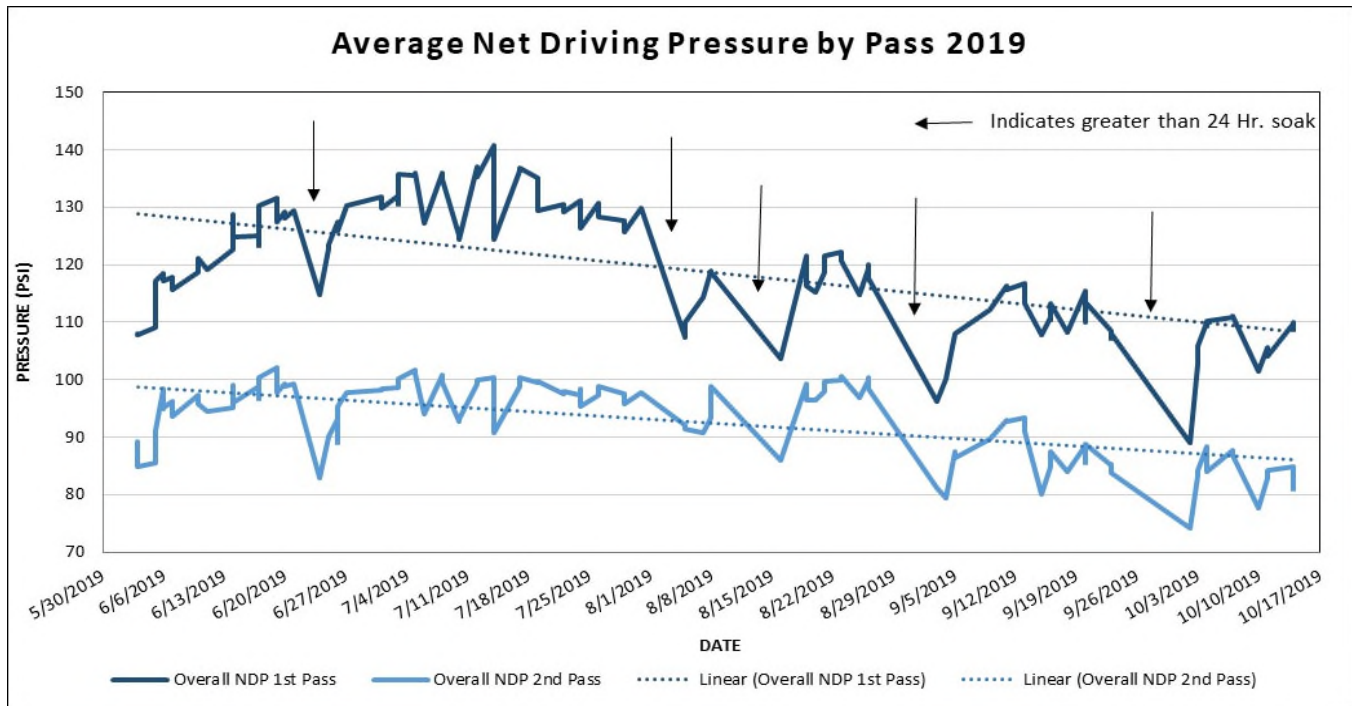
$$NDP_a = P_f - P_p - P_o$$

Where	NDP <sub>a</sub> = Average Net Driving Pressure
	P <sub>f</sub> = Average Feed Pressure (average of feed and concentrate pressures)
	P <sub>p</sub> = Pressure in the permeate line (gauge pressure)
	P <sub>o</sub> = Average Osmotic Back Pressure of feed water (average of feed and concentrate salt concentration divided by 100)

Generally, P<sub>o</sub> is calculated utilizing Total Dissolved Solids (TDS) values; however, for the Beal RO Plant this data is calculated utilizing the plant Specific Conductance (SC). This is done for convenience as plant in-process meters measure SC and because analysis of historic field data collected indicates that the relationship between SC and TDS is generally consistent.

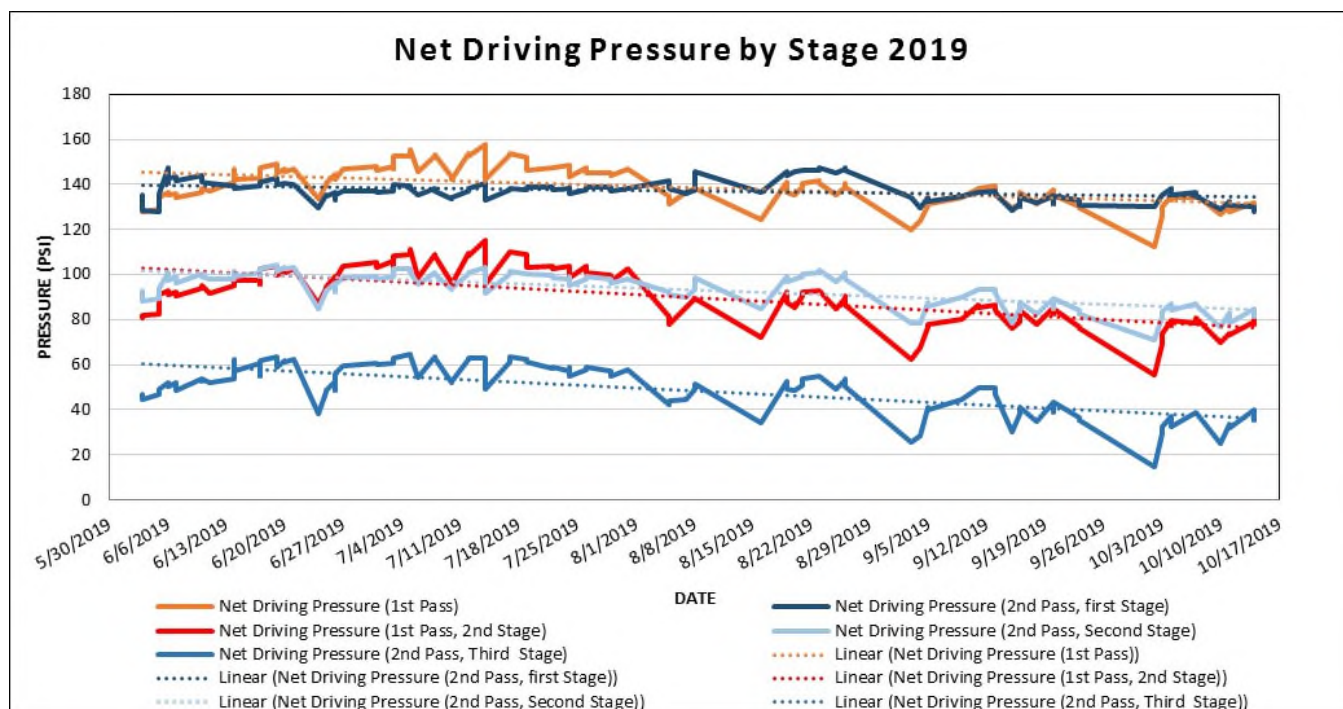
The NDP will begin to increase over time due to fouling or scaling of the RO membranes and it is common practice in the industry to instigate a membrane cleaning regiment when NDP increases by 15% to 25% above baseline value. Volatility and significant decreases in NDP can be due to variances in instrumentation (calibration of meters), errors made during data collection, significant system adjustments on nonautomated RO operations (such is the case a Beal), or influence from effective cleaning or soaking events.

When NDP is monitored for each stage of a RO system, problems can be identified between fouling and scaling based on the location of increases in pressure. An increase in NDP in the front stage of a RO indicates possible fouling issues while increases in NDP in a second stage indicates scaling. In general, average NDP increased over the first month of operation during the 2019 season then generally decreased during the second half of the operational season, ending at approximately the same value as at startup (**Figure 6**). **Figure 7**(below) displays NDP data for each array of the Beal RO system.



**Figure 6. Average Net Driving Pressure**

A slight overall increase in NDP would be expected in normal RO operations, particularly where systems are being operated near the upper limits of capacity for feed water chemistry, such as the case with the Beal RO system. The decreases in NDP throughout the second half of the season correlate with the mid-season cleaning (completed 08/05/2019) and the frequent system downtime which were used as soak events. It would appear that any fouling or scaling that may have occurred during the early season was removed by the midseason cleaning and that the frequent soak events resulted in minimal or no net accumulation of membrane fouling during the 2019 season. Additionally, the data tends to suggest that extended soaking periods can be nearly as effective as the cleaning events.



**Figure 7. Average Net Driving Pressure by Pass and Stage**

As stated above, evaluation of this type of data is complicated due to the everchanging feed water chemistry which results in continual system adjustments in order to maintain the appropriate flows and pressures. For most RO systems, feed water chemistry is generally consistent, so frequent system adjustments are not required which results in a much smoother graph.

Tetra Tech plans to continue the collection of RO data for the NDP calculation during future operations in order to develop better baseline data and the development of RO membrane cleaning protocols. Plant field data and the resulting calculated values for NDP are presented in **Appendix B – Tables 1 and 2**.

### Normalized Permeate Flow

The data was also utilized to calculate Normalized Permeate Flow (NPF) which is a comparison of RO permeate flow in the present operational conditions to the baseline permeate flow. The purpose of flow normalization is to account for variable input parameters such as net driving force and temperature, both of which have tremendous effect on permeate flows. The effect of these parameters is “normalized” to properly analyze the membrane performance.

Once NDP has been determined, NPF may be calculated based on NDP and temperature using the following equation:

$$NPF = \frac{(TCF \text{ today } ^\circ F) \times (NDP \text{ startup (PSI)}) \times (Permeate \text{ Flow (GPM)})}{(NDP \text{ today (PSI)}) \times (TCF \text{ startup } ^\circ F)}$$

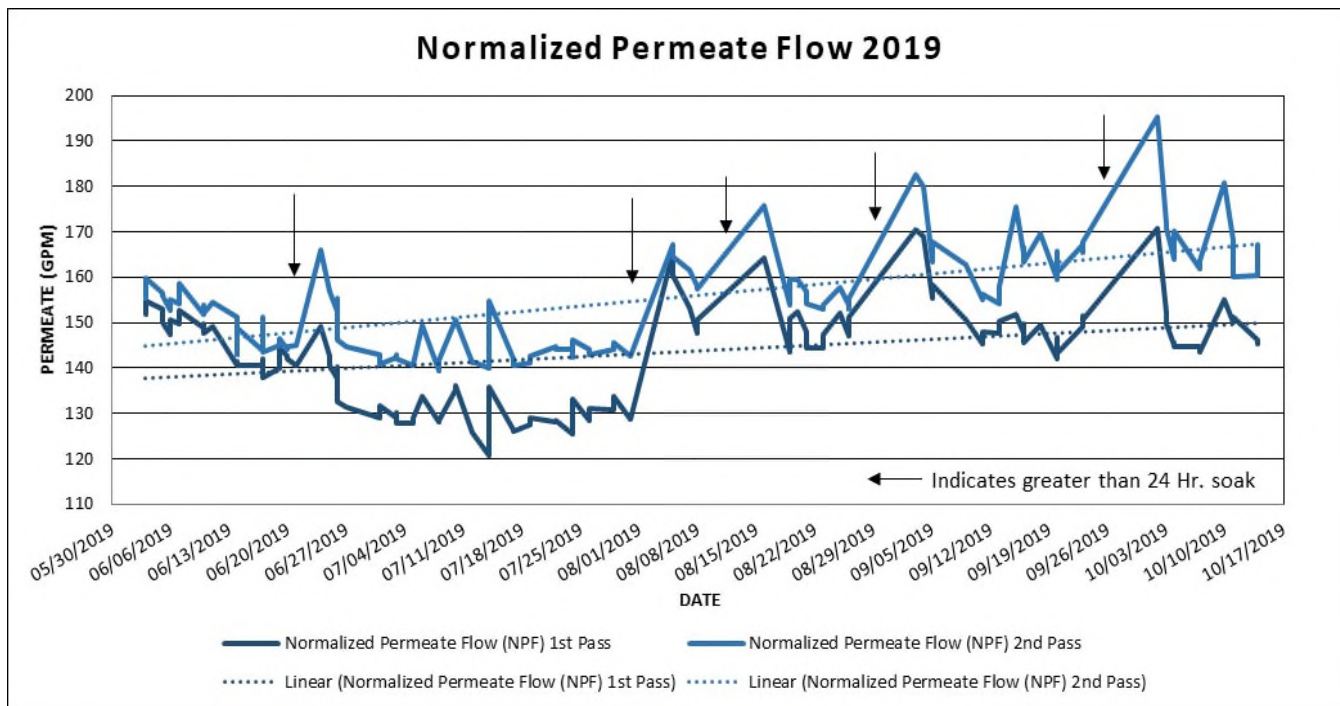
Where

NDP = Net Driving Pressure

NPF = Net Permeate Flow

TCF = Temperature Correction Factor (published values)

NPF measures the amount of permeate water that the RO is producing. A decrease in NPF could indicate that the membranes require cleaning while increases in NPF suggest either improved feed water quality (lower TDS), decreases in membrane foulant, possible leakage of brine seals or other membrane damage. NPF should always be evaluated with other operating parameters and take into account any system adjustments that also contribute to any NPF values. For instance, NPF increases combined with increased permeate conductivity may suggest brine seal leakage or membrane damage. In general, NPF in 1st and 2nd passes declined during the first month of operations, stabilizes during the second month, then increases through the remainder of the season (**Figure 8**). This suggests that during early season operations, fouling may have occurred. The removal of foulant during the mid-season cleaning combined with frequent soak periods associated with system down time resulted in improved system performance but still a slight net decrease in 1st pass membrane performance.



**Figure 8 Beal RO Normalized Permeate Flow**

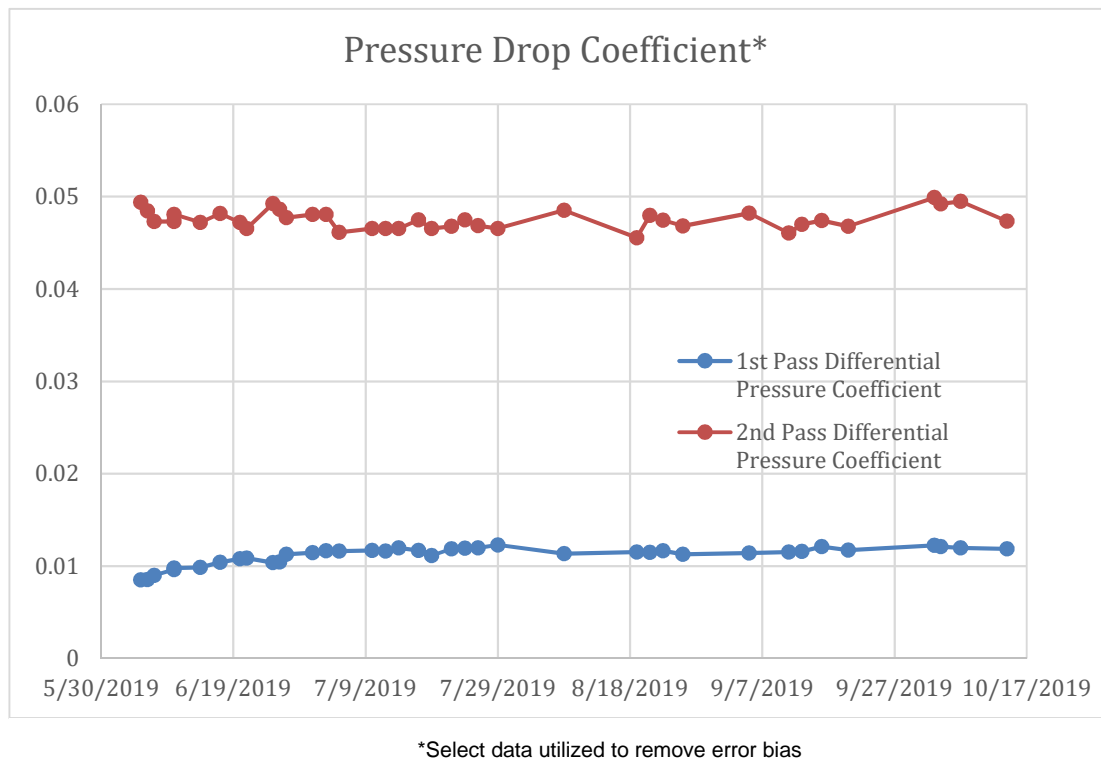
The data presented here is not definitive for several reason. The baseline for this data comparison was chosen as the season startup, which may contain significant bias. Second, the system was designed with a bypass line connecting first pass feed (raw water) and second pass feed (1<sup>st</sup> pass permeate) to help balance feed pressures to each booster pump. However, flows between the bypass line can vary significantly during operation which will alter the “normalization” of the data for second pass. Finally, system adjustments to operating pressures, flows, and permeate production will also impact the “normalization” values. When significant system adjustments were made, plant values were first recorded prior to those adjustments and then after to evaluate the effects of the adjustments on NDP and NPF. Plant field data and the resulting calculated values for NPF are presented in **Appendix B – Tables 1 and 2**.

### Differential Pressure Drop Coefficient

Differential pressure drop, is the difference between feed pressure and concentrate pressure, for a single array or pass. The Differential pressure drop coefficient attempts to normalize differential pressure for changes in flow.

$$\text{Pressure Drop Coefficient} = \frac{(\text{Pass Pressure Drop}(\text{psi}) \equiv [\text{Pass Feed Pressure} - \text{Pass Concentrate Pressure}])}{([\text{Pass Feed Flow}(\text{gpm}) + \text{Pass Concentrate Flow}(\text{gpm})]/2)^{1.5}}$$

In general, increases in the differential pressure drop coefficient are often used as an indicator of obstruction to flow (fouling) within the system. Foulant may be associated with particulates, biological growth, or dissolved solids precipitation (scale). Fluctuations in the coefficient can also be attributed to system adjustments, meter calibrations, feed and concentrate valve functionality, and system stabilization following shutdowns / restarts.



**Figure 9. Calculated Pressure Drop Coefficient**

Increases in the 1<sup>st</sup> pass differential pressure drop coefficient during the first month of operations supports possible membrane fouling followed by more stable performance; however, there were also significant system adjustments that occurred during the first few weeks of operation. The variability of 2<sup>nd</sup> pass coefficient values are likely due to operator adjustments to balance the system which resulted in fluctuations of the 2<sup>nd</sup> pass feed concentrations due to varying amounts of raw water passing through valve YV125A, instrument calibrations (flow meters and transducers), and issues associated with the deteriorating condition of the 2<sup>nd</sup> pass feed valve.

Tetra Tech plans to continue the collection of RO data for the differential pressure drop coefficient calculation during future operations in order to develop better baseline data and refine sampling protocols.

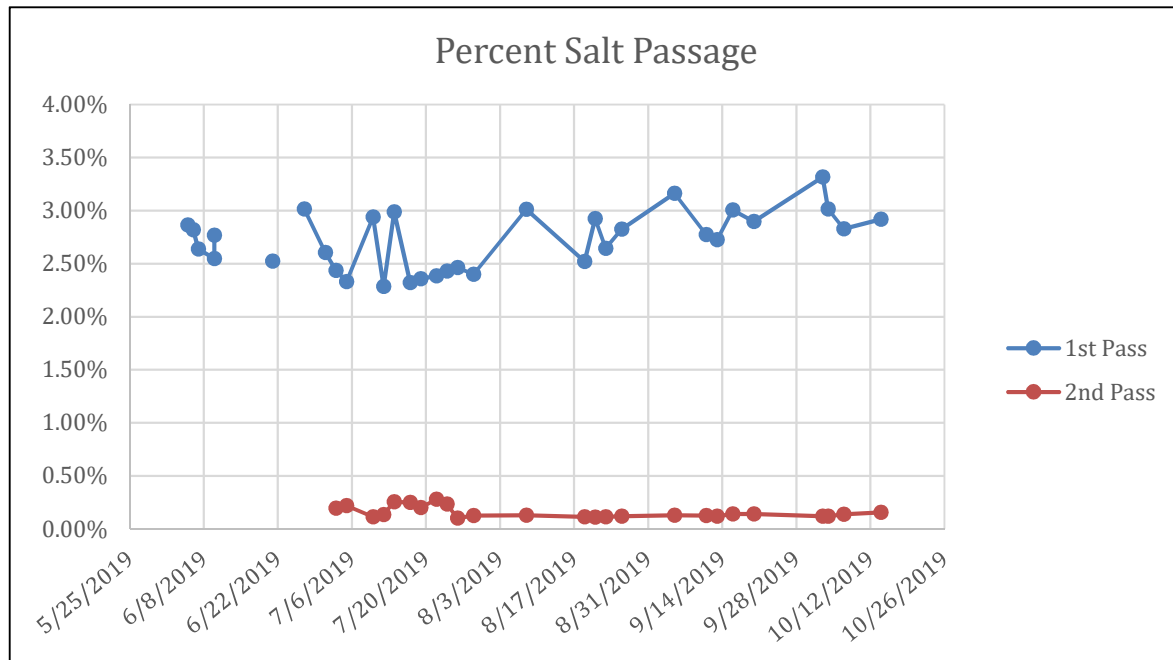
## Percent Salt Passage

Percent salt passage uses feed conductivity, concentrate conductivity, and permeate conductivity to evaluate membrane performance.

$$\% \text{ Salt Passage} = \frac{(\text{Pass Permeate Conductivity (SC)}) \times 2}{(\text{Pass Feed Conductivity (SC)} + \text{Pass Concentrate Conductivity (SC)})}$$

An increase in salt passage may be due to leaking brine seals, fouling, improper pH, high recovery rate, too high or low feed pressures, or changes in feed water chemistry. Initial evaluation of the relevant data collected during 2019 for this metric appears to suggest that 1<sup>st</sup> pass salt passage generally increases ( ) through the season and may suggest either membrane fouling/scaling or excessive operating feed pressure; however, significant system adjustments, instrument calibrations (SC meters), and operational constancy should be recognized as a significant contributor to the data variation. Second pass salt passage appeared to remain relatively stable throughout the season.

Tetra Tech plans to continue the collection of RO data for the percent salt passage calculation during future operations in order to develop better baseline data, evaluate membrane performance, and refine element cleaning protocols.



**Figure 10 Percent Salt Passage**

## Summary of RO Performance

Evaluation of the collective data for the RO during 2019 for net driving pressures, normalized permeate flows, salt passage, and differential pressure drop coefficient suggest the following:

- Mid-season cleaning was effective at removing early season fouling or scaling.
- Frequent extended soak events maybe nearly as effective as cleaning events resulting in minimal or no net fouling or scaling.
- The presence of the YV125A bypass and system adjustments to manage changes in feed chemistry must be considered when evaluating system performance metrics.

## Maintenance Tasks Completed During 2019

The RO system at Beal Mountain has completed its twelfth season of operation. Many of the system components are original equipment installs and due to their age, will have a higher probability for failure, especially when operating under the more strenuous conditions. Major maintenance projects completed in the 2019 operational season are listed below.

### Replacement of Second Pass Membranes

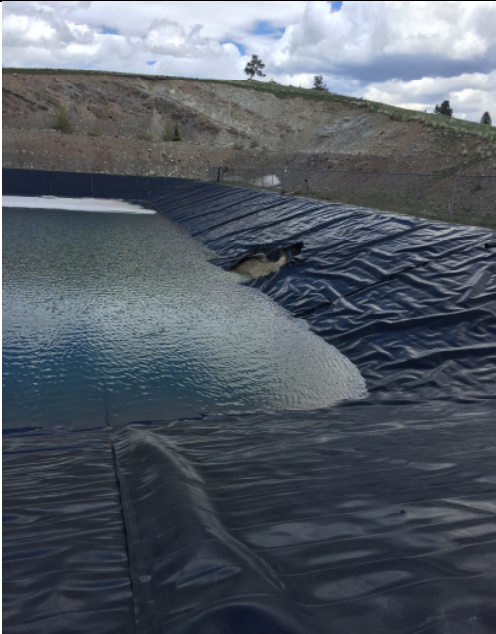

The 2018 Year 11 water treatment statement of work included a line item for the purchase and installation of 35 new second pass membranes. This work was not completed during the 2018 operable season; however, the replacement membranes were purchased under that statement of work. The replacement membranes were installed at the beginning of the 2019 operable season. During installation of the new membranes it was found that the new membranes have a smaller opening on the permeate port such that the membrane to vessel end cap adapter was not compatible. After a short delay, appropriate end cap adapters were obtained and installed without incident.

### Freshwater Pond Investigation

As part of the RO treatment process, permeate water is pumped from the RO Freshwater Storage tank to the freshwater pond located north of the RO building. The pond is utilized to provide the treated water additional exposure to air and sunlight in order to help reduce any residual ammonia (aeration of the water) or cyanide (hydrolyzed in sunlight). At the beginning of the 2018 operating season, a large tear in the Freshwater Ponds PVC liner was observed. Prior to contracting the repair of this liner further evaluation of liner integrity was deemed prudent.

The 2019 Year 12 water treatment statement of work included a line item for dewatering the Freshwater Pond with existing equipment in order to visually inspect the integrity of the synthetic liner. During the period of September and October 2019, the water level in the Freshwater Pond had been drawn down far enough to inspect and sample accessible sediments. Findings were as follows:

- Pond dimensions are approximately 250' x 250' x 50' deep with 1.75:1 slopes.
- The Liner material was compromised in multiple locations and consisted of rips, tears, and separated seams. Compromises were identified on all four pond slopes and at numerous elevations (i.e. above and below the typical water levels in the pond).
- Miscellaneous debris was observed at or near the bottom of the pond which included pipe, pipe fittings, and geotextile fabric.
- Sediment present was highly liquified with low cohesive strength.
- One shallow grab sample of sediment was obtained and submitted for laboratory analysis. Results indicate:
  - Non-detect for RCRA metals
  - Total Cyanide = 6.1 mg/kg
  - Weak acid dissociable cyanide = 0.5 mg/kg
  - Free cyanide =<4 mg/kg
  - Total Extractable Hydrocarbons = 988 mg/kg
    - <31 mg/kg C9-C18 Aliphatics
    - 321 mg/kg C19-C36 Aliphatics
    - 54 mg/kg C11-C22 Aromatics
  - 10.7% organic matter
- Total sediment depth estimated to be three feet but not confirmed. Therefore, sediment volume estimated to be 16,875 cubic feet (582 cubic yards).
- Chemistry of deeper sediments remains unknown.

Beal RO Room Sump Disposal System	
	
Photo 3. Tear in Freshwater Pond liner spring of 2018.	Photo 4. Freshwater Pond – September 2019.

### First pass reject valve replaced

Tetra Tech personnel purchased a replacement 1<sup>st</sup> pass reject valve and flanges which required custom welding and fabrication in order to fit the location. The original valve had been vibrating excessively during the past operating seasons and had become worn to the point that it is no longer functioning. The valve was fabricated and installed on August 2<sup>nd</sup> while the system is down for the mid-season membrane element cleaning.

### Second Pass feed valve replaced

Tetra Tech personnel purchased and replaced the 2<sup>nd</sup> pass feed valve on October 2<sup>nd</sup>, 2019. The valve, which was original to the system (2008), had become worn over time and began vibrating profusely shortly after startup during 2019 operations. Issues with the valve were most likely exasperated with the replacement of the 2<sup>nd</sup> pass membrane elements and system adjustments implemented to reduce the volume of raw water entering into the 2<sup>nd</sup> pass of the system.

### CIP heaters installed

Two heating elements and their related controls were installed in the CIP system on July 24<sup>th</sup>, 2019. The use of heated water for cleaning solution is recommended by the membrane manufacturers because it can be more effective and efficient at removing fouling. Installation included installing a temporary larger power supply cable to the Connex container and connecting heater controls to safety shutoff switches on the CIP.

### Freshwater Storage Tank pump impeller Replacement

On August 7<sup>th</sup>, the Beal RO unit experienced a system stoppage due to the failure of the impeller in the storage tank pump located immediately north of the Beal building. The pump and motor were removed and upon

inspection, it was discovered that the impeller had completely separated from the motor shaft adaptor. The cause of the damage was not discernable but may have been due to general fatigue as the pump and motor are original to the system (2008) or may have been caused from debris entering the pump from the storage tank as the tanks roof has degraded significantly in the past few years. Tetra Tech installed a temporary replacement pump which is undersized for this operation but continued to work throughout the season. Repair components were procured and installed during demobilization activities and the repaired pump will be installed prior to the 2020 operational season.

## **Exterior Lighting on South and West Building**

Additional LED outdoor lights were added to the exterior of the building during the 2019 operational year. One existing (partially functioning) light was replaced on the south side of the building and two (2) new units were installed on the west side to alleviate health and safety concerns associated with working at the site during dark hours.

## **RO PLC and SCADA Communication**

On August 11<sup>th</sup> at approximately 06:45, a significant electrical surge passed through the Programable Logic Controls (PLC) communications networks at both the RO Water Treatment Plant and at the extraction well located south of the plant. Tetra Tech personnel were notified of the plant shutdown via remote call system and traveled to the site to investigate. Upon arrival at the Beal Mountain site, severe thunderstorm activity was observed in the form of significant lightning, surface water runoff, and hail accumulations exceeding 6-inches. Initially, it was discovered that a pressure transducer located in the permeate water storage tank was not functioning (visible electrical scorching), PLC networks (three total) were not communicating, and the well Variable Frequency Drive (VFD) controller had faulted. Failed component replacement and system trouble shooting continued from August 11<sup>th</sup> through August 16<sup>th</sup> with help from our computer integration subcontractor Industrial System, Inc.

Industrial Systems is based in Vancouver, Washington but was able to remotely access the system to help identify faulty components and direct troubleshooting efforts. As damaged components were identified and replaced, it was discovered that additional components were either intermittently functioning or only partially functioning and needed repair or replacement. Finding replacement components was found to be especially challenging due to the “age” of the Beal RO unit. At 12-years in operation, the hardware platform of the PLC’s, Human Machine Interface (HMI), and communications systems are no longer manufactured or supported. The replacement components were procured through Industrial Systems and were generally remanufactured or factory certified used stock and were located through various vendors and suppliers. Additionally, most of the specialized hardware procured through Industrial Systems required programming that had to be completed through proprietary licensed software at their facility.

The system operated intermittently upon restart on August 16<sup>th</sup> through August 27<sup>th</sup> when the HMI unit stopped working altogether. Upon installation of a remanufactured HMI unit on September 4<sup>th</sup>, the system again ran intermittently through early October as various components were replaced and programming was altered to bypass problematic hardware. From August 12<sup>th</sup> through October 2<sup>nd</sup>, a period consisting of 53 days, the system was either non-operational or partially operational for 24 days and Tetra Tech personnel were onsite 30 days. During this time period, the following components were replaced/installed due to the electrical surge:

- Permeate Tank Pressure Transducer
- Upgraded communications transmitter for internet service
- Well PLC Input Module
- Main PLC Module
- VFD Pump Controller (swapped with onsite spare)
- HMI Unit
- Network Switches, Cables, and Router

- Main PLC Output Module
- Fiber Optic Network Module at Well and Plant
- Main PLC Module (Exchanged for warranty replacement)
- Allen-Bradley Power Supply
- Allen-Bradley Main PLC Chassis

The repair work following the lightning damage was extremely challenging due to the complexity of how the component failures manifested. The exact circumstances of the communication stoppages were rarely repeatable and generally were random. Following a repair, the system would often operate for a period of time (varying from hours to days) without incident but then would unexpectedly fault again. With each repair, it appeared the issues had been resolved, only to have a fault or communications failure cause the RO unit to shut down again. The work that Industrial Systems was conducting over the internet required Tetra Tech personnel to physically be onsite to monitor the system and perform physical tasks and testing needed to troubleshoot the system and complete the repair work.

## **System Maintenance Not Completed in 2019**

The 2019 Year 12 water treatment statement of work included a line item (Subtask 4C) for the replacement of RO system butterfly valves. This work was not completed in 2019 as it was deemed low priority when compared to unexpected costs associated with the August 11, 2019 lightning strike and subsequent communications issues.

## **Recommendations and Discussion**

Tetra Tech is making the following recommendations for future Beal RO water treatment plant operations:

### [Remove or Reconfigure Valve YV125A](#)

Tetra Tech recommends the removal or reprogramming of the “bypass” valve identified as YV125A. The purpose for the valve in the originally designed system was to return a portion of the 1st pass permeate back into 1st pass feed, which reduces influent contaminant concentrations and helps balance feed pressures between 1st and 2nd pass arrays.

Thirteen years of operating the RO system has resulted in higher contaminant concentrations in the leach pad influent. The degrading water quality has reduced the RO system capacity and has resulted in an opposite flow path through the YV125A valve (raw water is now being pushed through the valve into the 2nd pass feed waters). The problem was further exacerbated in 2019 when the 2nd pass membrane elements were replaced and the aging 1st pass elements were not able to supply adequate water to the 2nd pass of the system. This condition will shorten the life of the newly purchased second pass membranes and increase the possibility of a mass precipitation event in the 1st pass of the system, especially if the system is operated at higher production levels.

YV125A valve replacement will require rebuilding significant portions of the 1<sup>st</sup> and 2<sup>nd</sup> pass feed plumbing and will also require a new Variable Frequency Drive (VFD) controller for the 2<sup>nd</sup> pass booster pump. Alterations to the system PLC/SCADA programming will also be necessary. Tetra Tech is currently in the process of identifying the available options and costing where possible.

### [Replace First Pass Membrane Elements](#)

The 1<sup>st</sup> pass consists of 2-stages; stage 1 includes the “A” and “B” Arrays with 4 vessels in each array containing 6 elements per vessel for a total of 48 membrane elements, and stage 2 consists of the “C” Array with 4 vessels containing 6 elements per vessel for a total of 24 membrane elements. In 2009, all 24 of the “C” array membranes were replaced due to significant scaling. In 2012, all 72 of arrays “A”, “B” and “C” membrane elements were replaced due to with severe scaling, and in 2015, 27 membrane elements were replaced in Arrays “A” and “B” in various locations due to significantly higher than average element weights.

Tetra Tech recommends the replacement of all 72 1<sup>st</sup> pass RO membrane elements in order to maximize the production of 2<sup>nd</sup> pass permeate water, reduce the level of solution in the Beal heap leach pad, extend the life of the new (2019) 2<sup>nd</sup> pass membrane elements, and provide a new operational baseline (point of comparison for operational adjustments) reflective of the current raw water conditions.

#### [Replace Media in MMF Vessels 100, 200, and 300](#)

The media material in the Multi Media Filters (MMF's) has not been changed since the construction of the RO system in 2008. The media consists of a gravel layer which covers the underbed plumbing, a 3-inch thick garnet sand layer, a 24-inch thick greensand layer, and a 12-inch thick anthracite layer. Testing of the media in 2016 identified that the greensands are no longer functioning, and that pretreatment media has generally degraded in size which reduces flow capacity, filtering efficiency, and backwash effectiveness through the media.

Tetra Tech RO experts have reviewed laboratory and operational data from the past few operational seasons and have concluded that the greensand media is no longer needed in the MMF configuration due to the Total Iron, Ferrous Iron, and Manganese complexation with cyanides.

Tetra Tech recommends replacing the original media with different products that will provide greater filtering capacity and increased flow capacity. This is especially important because replacement of the 1<sup>st</sup> pass membrane elements and removal of the bypass valve YV125A will necessitate maximum 1<sup>st</sup> pass production which in turn requires achieving the original design raw water feed flow through the MMF's.

#### [Replace RO SCADA Computer and Upgrade Software](#)

Tetra Tech recommends the replacement of the SCADA computer and associated system software. The current computer uses Microsoft Windows 7. During 2019, Microsoft reduced support for Windows 7 and will completely discontinue support in June of 2020. The Microsoft action has led other windows-based software manufactures, such as the WonderWare used by the SCADA program and the Rockwell software utilized by the Human Machine Interface (HMI), to stop support of their software versions for the Windows 7 operating system as well. In addition, the Beal RO SCADA computer has operated in extremely challenging conditions including dirty/dusty air, high humidity, and several plumbing failure events which resulted in complete saturation of the machine. These conditions have resulted in unstable computer operations and increased potential for cyber-attack.

#### [Mid and End of Season Cleanings](#)

Routine RO membrane maintenance is required to optimize the life span of membrane elements, deliver efficient RO operation, and minimize system pressures which will prolong the life of other system components such as pumps and valves. Membrane maintenance includes the practice of "soaking" elements, permeate rinses with CIP, and chemical cleaning. Historically, the Beal RO elements received an end-of-year cleaning and occasionally, when production rates were high, a mid-season cleaning as well. Due to the concentration of contaminants in the solution being treated at the Beal RO water treatment plant, Tetra Tech strongly recommends membrane elements undergo periodic permeate soak events along with a mid and post season cleaning. The midseason cleaning will be utilized to remove accumulated foulants which will maximize membrane life, membrane operational efficiencies, and reduce operational pressures. Every RO system is different and faces a unique cocktail of constituents to remove during the cleaning process, making an exact protocol for chemical usage and cleaning procedure impossible to generically template. However, Tetra Tech continues to identify and develop procedures which are tailored to the Beal site since the CIP purchase in 2017.

The post season cleaning should include the additional step of membrane preservation by pumping a 1% sodium metabisulfite (by weight) solution through the system which is required for proper storage of the membrane elements.

### *Dedicated CIP Equipment Area*

Tetra Tech recommends the construction of a dedicated area within the existing RO building for operation and storage of the CIP system. This approach would greatly reduce hazards (Slips, Trips, and Falls) created by hoses connecting the CIP (currently in Connex storage container) and the RO system as well as hazards associated with ice formation on walking surfaces during cleaning operations conducted during the latter portions of the season. Additionally, relocation of the CIP system would allow for safe working space when adding chemicals to the CIP system.

### *Remove Permeate Storage Tank Cover and Clean Tank*

2<sup>nd</sup> pass permeate water from the RO system is transferred into a large steel Freshwater Storage tank located just north of the RO building. The tank was originally part of the Beal Mountain Mine operation and was incorporated into the RO operations to provide surge and storage capacity for RO operations including the ability to provide water for membrane flushing and cleaning operations, both of which require extremely clean water (i.e. 2<sup>nd</sup> pass permeate) in order to be efficient and prevent further damage to the membrane elements.

During mine operations, an insulated ceiling was installed on the tank which consisted of placing sheet Styrofoam and oriented strand board (OSB) over openings at the top of the tank. The OSB is now degraded and large pieces have been blown off or fallen into the tank from the roof. The debris in the tank can be problematic because it can block the transfer pump outlet and fouls the permeate water needed during membrane maintenance activities.

Tetra Tech recommends removing the remaining roofing material. Additionally, Tetra Tech recommends accessing the tank interior and pressure washing the lower portions of the tank to remove debris.

### *RO System Butterfly Valve Replacement*

Tetra Tech recommends that butterfly valves in the RO system be replaced prior to the start of the system in 2020. The valves are an important component in the RO system and utilized to divert process waters within the system when in operation as well as isolate portions of the system during various cycles of RO operations. All of these valves are original to the system and have reached the end of their operational expectancy. At least two of the valves were identified as allowing fluid to pass while in the closed position while performing system check valve inspections and replacement activities in 2018.

### *Freshwater Pond Level*

Results of the 2019 investigation identified numerous compromises in the liner material of the Freshwater Pond. Tetra Tech recommends the Upper Pond be kept as low as operationally possible during the 2020 water treatment season to minimize the quantity of water that may be entering the groundwater system in that area.

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## APPENDIX A – WATER LABORATORY ANALYSIS

## APPENDIX B – 2019 OPERATIONAL FIELD DATA

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**To:** Sonny Thornborrow, US Forest Service

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**From:** Randal English

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**Date:** May 28, 2020

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**Subject:** Yearly Operations Summary – 2019 Beal Year 12 RO Treatment Season

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**Contract:** GS-00F-168CA (Order 12034319F0152)

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Tetra Tech is pleased to submit this Yearly Operations Summary – 2019 Reverse Osmosis (RO) Year 12 Water Treatment Season for the Beal Mountain Mine located 16 miles west southwest of Butte, Montana, in Silver Bow County. This yearly report is required as a deliverable for Task 6 of the Beal Mountain Mine Year 12 Work Order. Data reported includes water volumes treated through the RO Treatment System, heap leach solution level monitoring, and heap leach laboratory and field solution chemistry analytical results.

### **TOTAL LEACH PAD SOLUTION VOLUME TREATED BY RO**

The Beal RO Water Treatment system activities began May 3, 2019 with the restoration of power to the site following snow removal. On May 14<sup>th</sup> Tetra Tech mobilized to the site and began assembling the RO plant and began circulating from the extraction sump (Sump-1) to the reject sump (Sump-3A) in order to clean any accumulated scale from the pipes and begin blending the stratified (presumably) leach pad solution. Full mobilization efforts began on May 17, 2019, with the mobilization of membranes to the site and subsequent plant assembly. The RO system was started on May 30, 2019, and full-scale water treatment began on May 31<sup>st</sup> following minor system repairs. Minor system repairs included pressure gauge checks, pressure transducer calibration, meter calibration, and addressing a non-functioning transducer on the Fresh Water Storage Tank.

At startup, the water treatment totalizer meter reading was reset to zero (0) gallons. The Year 12 contract called for the RO System to produce 18 million gallons of treated water. A contract modification (Mod #1 dated August 28, 2019) authorized the production of an additional 4 million gallons of treated water. The treatment season ended October 14, 2019, with the plant 2<sup>nd</sup> pass permeate (treated water) meter reading 22,006,682 gallons. This is the actual treatment volume for the Year 12 water treatment season. Total treated water produced to date is 234,932,106 gallons.

Heap leach solution elevation in Sump 1 was measured on May 9<sup>th</sup>, 2019 at 7491.45 feet; the solution elevation at the end of the treatment season on October 14<sup>th</sup>, 2019 was 7,482.26 feet.

### **BEAL RO SYSTEM OPERATIONS**

The multi-stage, semi-permeable membranes are the primary contaminant removal component of the Beal Mountain RO system. A membrane functions when influent water is supplied to the membrane surface at a pressure greater than the osmotic pressure of the solution being treated. This creates a significant pressure differential across the membrane, forcing water molecules through the membrane. The pore size on the membranes restrict the passage of impurities, bacterium, and ions larger in size than the pores of the membrane. The solution that passes the membranes is called “permeate”, the remaining solution is referred to as “reject”.

The concentration of contaminants in the solution being treated dictates the operating pressure on the membranes. A higher contaminant load requires higher operating pressure due to the higher osmotic pressure exerted by the water and the dissolved solutes. When operating at elevated pressures, the system must be closely monitored to avoid damaging the membranes. Damage can occur when excessive pressure is applied to the membranes and the differential pressure between the feed side and the permeate side becomes too high, so that ions are forced into the membrane pores or the reject water becomes so highly concentrated that it can no longer keep the ions and molecules suspended in solution resulting in precipitate formation. This precipitation forms solid molecules and is often referred to as membrane “scaling” or “fouling”. Significant scaling greatly reduces the operational capacity of a membrane element, as well as the overall life cycle of a membrane. Meticulous attention must be paid to operational parameters and diligent system adjustments must be made to prevent catastrophic scaling from occurring when operating RO systems near the upper limits of their design capacities, such as the scenario at the Beal RO plant. To operate at the upper limits of design, the amount of permeate needs to be reduced in order to keep solution concentrations in the reject below the point of mass precipitation.

Regular membrane cleaning regiments can be employed to remove minor amounts of scale and fouling. One of the membrane cleaning options include “soaking” the RO membranes (1<sup>st</sup> Pass, 2<sup>nd</sup> Pass, or Both) in 2<sup>nd</sup> pass permeate water (treated water). This process involves pumping stored 2<sup>nd</sup> pass permeate water into the membrane vessels while monitoring the Specific Conductance (SC) of the reject water. Permeate water is pumped into the vessels until the SC measurements of the reject water from those vessels are observed to be at or near the SC values of the water being pumped in. The membrane elements are then allowed to soak in the clean water for approximately 18 to 24 hours. This allows salts and other dissolvable constituents, along with micro fine particulates, to be removed from the membrane surfaces and pore spaces, improving membrane efficiency and reducing the probability of a mass scaling event to occur. The practice of “soaking” the membranes is widely accepted amongst water treatment professionals and is highly recommended by Tetra Tech’s RO experts who are familiar with the current RO configuration and have evaluated the chemical constituents of the Beal RO raw water. Another membrane cleaning option utilizes specially formulated chemicals of low pH (2 – 3) and high pH (10 - 11) mixed in solution. The solutions are then pumped and recirculated through each array of the system at a targeted flow and pressure which allows the solution to scour out precipitates and fouling. Both cleaning regiments were employed during the 2019 water treatment season and are further discussed under section Membrane Cleaning below.

## **Beal RO System Operational Efficiencies**

The volume of treated water was monitored and recorded using the Beal RO system computer software data logger. Tetra Tech has calculated an estimated net effective efficiency for the 2019 RO operations by extracting flow data from the RO influent and 2<sup>nd</sup> pass permeate lines (total gallons solution in and total gallons 2<sup>nd</sup> pass permeate out). The data set consisted of extracting flow meter readings (gpm), at sixty-minute intervals, from archived computer data. The entire 2019 treatment season’s influent and 2<sup>nd</sup> pass permeate flow data was then averaged and divided to produce a single estimate of the efficiency at which the RO treats heap leach pad water. In 2019, it is estimated that for every gallon of water entering the RO system, 0.47 gallons of water was produced as 2<sup>nd</sup> pass permeate, as compared to 0.44 gallons in 2018 and 0.39 gallons in 2017. The values calculated are to be considered as estimates because this method does not account for situations where influent water is not fully processed to produce permeate such as while backwashing the Multi Media Filters (MMF’s) or during startup cycles prior to the system coming fully online. The treatment volumes for years 2008 – 2019 are summarized below in **Table 1**.

**Table 1. 2019 Yearly RO Total Treated Water (2nd pass permeate) Summary**

Year	<sup>1</sup> Total Days	Total Gallons Treated (2 <sup>nd</sup> pass permeate)	Average Treatment Rate (gpd 2 <sup>nd</sup> pass permeate)	<sup>2</sup> Approximate Net Effective Efficiency (%)
2008	61	12,007,550	196,845	45%
2009*	119	25,377,606	213,257	46%
2010	130	33,638,532	258,758	44%
2011	147	32,136,432	218,615	46%
2012*	119	24,959,896	209,747	48%
2013	79	13,881,032	175,709	46%
2014	86	14,712,416	171,075	46%
2015*	64	11,295,392	176,491	45%
2016	73	13,188,800	180,668	44%
2017	84	13,500,660	160,722	39%
2018	110	18,227,100	165,701	45%
2019*	98	22,006,682	224,558	47%

\* Indicates year where membranes were replaced. (24 in 2009; 87 in 2012; 27 in 2015; 35 in 2019)

<sup>1</sup> Days of operation were estimated utilizing archive data from RO computer. Total excludes scheduled maintenance including RO membrane soaking periods.

<sup>2</sup> Based on archive data from Beal RO computer. Data is considered estimated due to being derived from season-long averages of flow streams.

Average 2<sup>nd</sup> pass permeate production rates increased significantly in 2019 with an average daily production rate of 224,558 gallons 2<sup>nd</sup> pass permeate produced. Historic average daily production rates range from 160,722 gallons per day in 2017 to 258,758 gallons per day in 2010. Average 2<sup>nd</sup> pass permeate rates were calculated by dividing the total 2019 2<sup>nd</sup> pass permeate production by the estimated number of full days the plant was in operation, not counting downtime during MMF backwashes or down time during maintenance activities. These production rates should be considered approximate.

The Beal RO system was originally designed for 66% permeate extraction (maximum) through the first pass of the system. That 1<sup>st</sup> pass permeate (66% of original raw) is then sent to the 2<sup>nd</sup> pass of the system where it was designed to extract 90% permeate (maximum) (90% of the 1<sup>st</sup> pass permeate), resulting in a maximum possible net efficiency of 59.4%. This was based on the data collected during the RO pilot project conducted in 2006. The Beal RO water treatment system is currently being operated with 50 – 60% permeate extraction in first pass followed by 60 – 70% permeate extraction in second pass to keep the system pressures at a safe level, prevent equipment damage, and avoid potential scaling. The primary driver for the reduction in the 2<sup>nd</sup> pass recovery is the reverse flow condition present at the YV125A bypass valve. The purpose for the valve in the originally designed system was to return a portion of the 1<sup>st</sup> pass permeate back into 1<sup>st</sup> pass feed, which reduces influent contaminant concentrations and helps balance feed pressures between 1<sup>st</sup> and 2<sup>nd</sup> pass arrays. Thirteen years of operating the RO system has resulted in higher contaminant concentrations in the leach pad influent. The degrading water quality has reduced the RO system capacity and has resulted in an opposite flow path through the YV125A valve. Raw water is now being pushed through the valve into the 2<sup>nd</sup> pass feed waters which

degrades the 1<sup>st</sup> pass permeate water quality. This results in the Beal RO system being operated between 43% and 51% net efficiency. The data presented in **Table 1** above was derived through collecting “snapshots” (once every sixty minutes) of flow rates and averaging them into a single number; therefore, it is an approximation which does not account for system operational variability.

## Beal RO System Operational Availability

The RO system availability is summarized in **Table 2** and is further described below.

**Table 2. RO Treatment System Availability Summary**

Date	Cause of Shutdown	Duration
06/11/2019	Low Power Quality	~ 0.2 Day
06/22/2019 – 06/24/2019	System shutdown for membrane soak	~ 3 Days
07/06/2019	Low Power Quality	~ 0.75 Day
07/09/2019 – 07/10/2019	Low Power Quality	~ 1 Day
07/13/2019 – 07/14/2019	Low Power Quality – T-storm	~ 1 Day
07/31/2019 – 08/05/2019	Membrane soak and Mid-Season Cleaning	~ 5 Days
08/07/2019	RO Surge Tank Pump Impeller	~ 0.5 Day
08/11/2019 – 08/15/2019	Low Power Quality – lightning strike; multiple communication losses and Programmable Logic Controller (PLC) faults; membrane soak while system down	~ 5 Days
08/19/2019	PLC/Supervisory Control and Data Acquisition (SCADA) Communication issues	~ 0.25 Day
08/20/2019	PLC/SCADA Communication issues	~ 0.25 Day
08/25/2019	PLC/SCADA Communication issues	~ 0.25 Day
08/27/2019 – 09/04/2019	PLC/SCADA Communication issues; membrane soak while system down	~ 8 Days
09/09/2019	PLC/SCADA Communication issues	~ 0.5 Day
09/14/2019 – 09/15/2019	PLC/SCADA Communication issues	~ 1.5 Day
09/17/2019 – 09/18/2019	PLC/SCADA Communication issues	~ 0.75 Day
09/23/2019	Low Power Quality	~ 0.2 Day

09/25/2019 – 10/02/2019	PLC/SCADA Communication issues; membrane soak while system down	~ 7.75 Day
10/09/2019 – 10/10/2019	PLC/SCADA Communication issues and frozen pipes	~ 1.75 Days

During the 2019 treatment season, there were numerous unanticipated shutdowns of the RO system due to power quality issues, PLC communications issues (following lightning strike), and mechanical failures.

#### **1<sup>st</sup> Shutdown – Low Power Quality**

Tetra Tech arrived on-site on June 11<sup>th</sup> following notification from the RO system that the unit was down. It was determined that the system shutdown was caused by a “Low Power Quality” fault likely due to a power bump rather than full loss of power.

#### **2<sup>nd</sup> Shutdown – Operator initiated Shutdown for Membrane Soak**

The RO system was intentionally shut down on June 21<sup>st</sup> for a 48-hour membrane soak. Second pass permeate was pumped through 1<sup>st</sup> pass (both stages) and 2<sup>nd</sup> pass (all 3 stages) utilizing the clean in place (CIP) system at the flow and pressure recommended by the element manufacturer. The system was restarted June 24<sup>th</sup>.

#### **3<sup>rd</sup> Shutdown – Low Power Quality**

Tetra Tech arrived on-site on July 6<sup>th</sup> following notification from the RO system that the unit was down. It was determined that the system shutdown was caused by a “Low Power Quality”, low voltage fault at the RO plant and a well fault on the frequency drive at the well head, which was most likely due to a brief systemwide power loss. The system was restarted on July 6<sup>th</sup>.

#### **4<sup>th</sup> Shutdown – Low Power Quality**

Tetra Tech arrived on-site on July 10<sup>th</sup> following notification from the RO system that the unit was down. It was determined that the system shutdown was caused by a “Low Power Quality”, power failure. The system was restarted on July 10<sup>th</sup>.

#### **5<sup>th</sup> Shutdown – Low Power Quality**

Tetra Tech arrived on-site on July 14<sup>th</sup> following notification from the RO system that the unit was down. It was determined that the system shutdown was caused by a “Low Power Quality” fault likely due to a power bump rather than full loss of power. The sensitivity of the power sensor was slightly reduced, and the system was restarted.

#### **6<sup>th</sup> Shutdown – Operator initiated Shutdown for Membrane Soak and Mid-Season Cleaning**

The RO system was intentionally shut down on July 31<sup>st</sup> for a 24-hour membrane soak prior to the start of the mid-season cleaning. The precleaning soak was utilized to enhance the effectiveness of the cleaning chemical used during the midseason cleaning through removal of dissolvable constituents and micro fine particulates. Upon completion of mid-season cleaning activities, several maintenance items were undertaken including removal and repair of a stainless-steel pipe manifold and the fabrication and installation of the replacement 1<sup>st</sup> pass reject valve. The system was restarted on August 5<sup>th</sup>.

#### **7<sup>th</sup> Shutdown – RO Surge Tank Pump Failure**

Tetra Tech arrived on-site August 7<sup>th</sup> following notification from the RO system that the unit was down due to a “Remote Run Disable” alarm. Tetra Tech personnel began troubleshooting the system to identify the source of the alarm which is generic to any unexpected condition controlled by the desktop SCADA. Final diagnostic of the alarm determined that the RO Freshwater Storage tank (permeate tank) had been filled to the failsafe limit set in the SCADA due to a failure of the pump impeller on the tank discharge pump. The failed pump and motor were

removed from service and a spare unit was retrofitted to temporarily work in its place. Additionally, during the shutdown Tetra Tech personnel initiated a manual flush of the 1<sup>st</sup> pass membranes to ensure the thorough removal of raw and concentrate waters. During the flush cycle, a 2-inch fitting failed on the flush pump and began spraying water throughout the front portion of the RO building. The flush cycle was immediately terminated, and the failed piping was repaired. The manual flush cycle was reinitiated and completed without incident.

### **8<sup>th</sup> Shutdown – Lightning Strike**

On August 11<sup>th</sup>, following severe thunderstorm activity in the area, Tetra Tech personnel checked the operational status of the RO system by remote login to the SCADA system. The system appeared nonoperational and several anomalies were observed on the SCADA computer, however, the system had not initiated the remote notification protocol of automated phone calls. Tetra Tech personnel immediately mobilized to the site and upon inspection, found that the SCADA had identified a low inlet pressure alarm and multiple communication loss faults from various components of the system.

System troubleshooting over the next several days identified burnt circuitry in the Freshwater Storage tank pressure transducer, damaged fuses in both the main PLC cabinet and well head PLC cabinet, fault at the well pump variable frequency drive (VFD) control, fault on the well head flow meter, nonresponsive well head PLC communications module, and burnt circuitry on one of the main PLC input modules at the RO plant. Replacement components were procured, installed, and the system was restarted on August 16<sup>th</sup>.

Tetra Tech personnel continued trouble shooting the system faults and replaced or repaired the observed damaged components as they were identified. The repair work following the lightning damage was extremely challenging due to the complexity of how the component failures manifested. The exact circumstances of the communication stoppages were rarely repeatable and generally were random. Following a repair, the system would often operate for a period of time (varying from hours to days) without incident but then would unexpectedly fault again. With each repair, it appeared the issues had been resolved, only to have a fault or communications failure cause the RO unit to shut down again. The work that Industrial Systems was conducting over the internet required Tetra Tech personnel to physically be onsite to monitor the system and perform physical tasks and testing needed to troubleshoot the system and complete the repair work.

### **Multiple Shutdowns – PLC/SCADA Communication Failure**

During the period of August 19<sup>th</sup> through October 10<sup>th</sup> the system experienced numerous unscheduled shutdowns. Table 2, above, provides a synopsis for the frequency and approximate duration of system shutdowns and failures which continued to plague the Beal RO PLC and SCADA network following the August 11<sup>th</sup> event.

Shutdown durations ranged from a few hours up to 8 days. With the exception of a short duration shutdown on September 23<sup>rd</sup> due to a power quality issue, all shutdowns during this period were associated with ongoing electronic system communication issues as a result of the lightning strike on August 11<sup>th</sup>. During this period, Tetra Tech replaced the following components: multiple PLC and input modules in the main PLC cabinet, main PLC rack and power supply, Human Machine Interface (HMI) screen, network router, all network switches, most ethernet cables, added necessary hardware to isolate internal system communications from the internet by routing through a designated fiber optic line. Repair of the system was further complicated by the fact that finding replacement components was found to be especially challenging due to the “age” of the Beal RO unit. At 12-years in operation, the hardware platform of the PLC’s, Human Machine Interface (HMI), and communications systems are no longer manufactured or supported. The replacement components were procured through Industrial Systems and were generally remanufactured or factory certified used stock and were located through various vendors and suppliers. A more detailed progressive analysis is presented in the “Maintenance Tasks Completed During 2019” section of this report.

### Other Minor System Stoppages

Other minor system stoppages occurred during the 2019 treatment season. For example, brief shutdown and restarts needed during PLC programming changes, cartridge filter replacement, or minor maintenance activities. These stoppages did not significantly affect the system operational availability.

It is estimated that the RO system was operationally available 72% of the time during 2019. This rate was calculated based on 137 days of potential full-scale operation (May 31 to October 14) compared with approximately 98 days of actual operation due to the downtimes noted above. Overall, the RO system downtime was minimized due to significant effort by Tetra Tech and its subcontractor (Industrial Systems Inc.).

Historic RO system operational availability has been as follows:

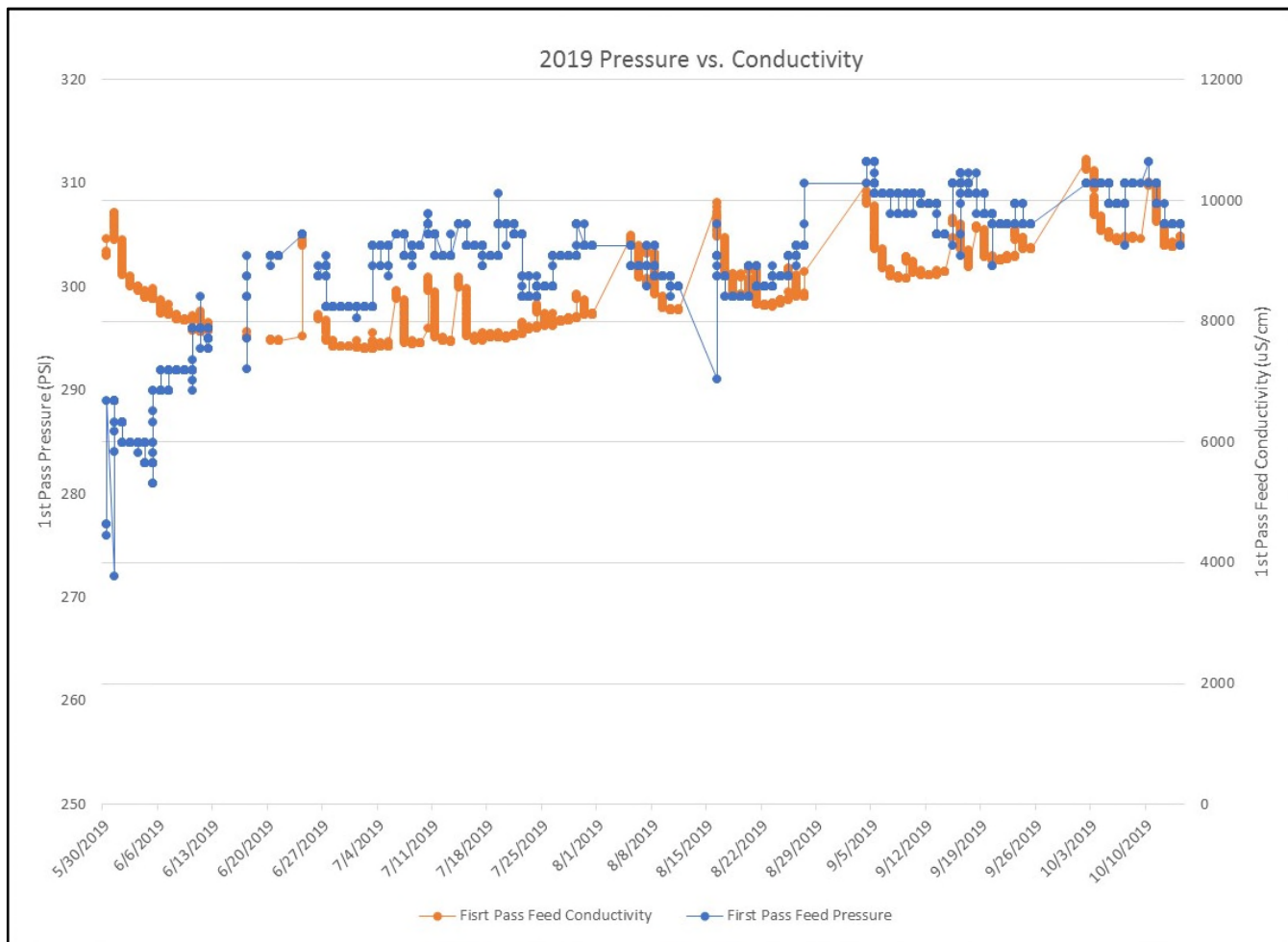
2009 - online 76% of the time  
2010 - online 96% of the time  
2011 - online 97% of the time  
2012 - online 97% of the time  
2013 - online 94% of the time  
2014 - online 91% of the time  
2015 - online 92% of the time  
2016 - online 95% of the time  
2017 – online 95% of the time  
2018 – online 92% of the time  
2019 – online 72% of the time

### BEAL RO SYSTEM WATER QUALITY

#### **General Water Quality**

2019 Beal RO Plant influent water quality was consistent with that observed during previous water treatment seasons. As has been observed in the past, influent water contained elevated Specific Conductance (SC) levels (around 10,000  $\mu\text{S}/\text{cm}$ ) during initial seasonal operation followed by a slow decrease to approximately 7,500  $\mu\text{S}/\text{cm}$  within the first two weeks of operations. During each of the many shutdown periods of 2019, the conductivity would rebound then rapidly decrease upon restart. The longer the shutdown period, the greater the rise in conductivity. This pattern continued throughout the season. A gradual increase in SC was also observed, with an ending value of approximately 9,200  $\mu\text{S}/\text{cm}$  when the plant was shut down on October 14<sup>th</sup>, 2019.

**Figure 1** below illustrates the relationship between 1<sup>st</sup> pass pressures and 1<sup>st</sup> pass (raw water) conductivity where pressure in the 1<sup>st</sup> pass generally increases as water conductivity increases. However, unlike previous treatment seasons where 1<sup>st</sup> pass pressure fluctuations generally coincide with raw water conductivity, pressures at the start of the 2019 treatment season appear lower and increased over subsequent weeks of RO operation, even though the raw water conductivity was initially decreasing. This abnormality was the result of system operational adjustments which were instituted to maximize the 1<sup>st</sup> pass permeate production and minimize the volume of raw water entering the 2<sup>nd</sup> pass feed through the systems balancing line, although these adjustments resulted in higher than normal operating pressures for 1<sup>st</sup> pass (approximately 280 psi in 2018 vs approximately 305 psi in 2019). The elevated flows through the balancing line resulted from the installation of the new second pass membranes which required higher permeate flows (2<sup>nd</sup> pass feed) than the older 1<sup>st</sup> pass membranes could provide. Several smaller spikes in the raw water conductivity can be observed in **Figure 1** which correlate to short term system shutdowns as described in **Table 2** above. Although system adjustments can help alleviate elevated pressures in the RO system, increased raw water conductivity (in general) will cause increases in the RO operating pressures.



**Figure 1 First Pass Pressure Compared with Raw Water Conductivity**

## Laboratory Chemical Analysis

Tetra Tech collected 2 (two) raw influent water samples for analysis according to Table 6 of Tetra Tech's 2012 Reverse Osmosis Water Treatment Plant Sampling and Analysis Plan (WTSAP) (Tetra Tech 2012) during the 2019 treatment season. The first sample was collected during the first week of full-time plant operations (June 6<sup>th</sup>) and the second sample was collected at the end of seasonal RO operations (October 7<sup>th</sup>). Both samples were submitted to Energy Laboratories, Inc. of Helena, Montana, for analysis. Four additional raw influent water samples were collected every other week and submitted for laboratory analysis according to an abbreviated Table 6 of Tetra Tech's 2012 WTSAP. **Table 3** shows the results of the raw influent water samples collected during the 2019 treatment season. Laboratory results are presented in **Appendix A**.

**Table 3. Raw Influent Water Samples**

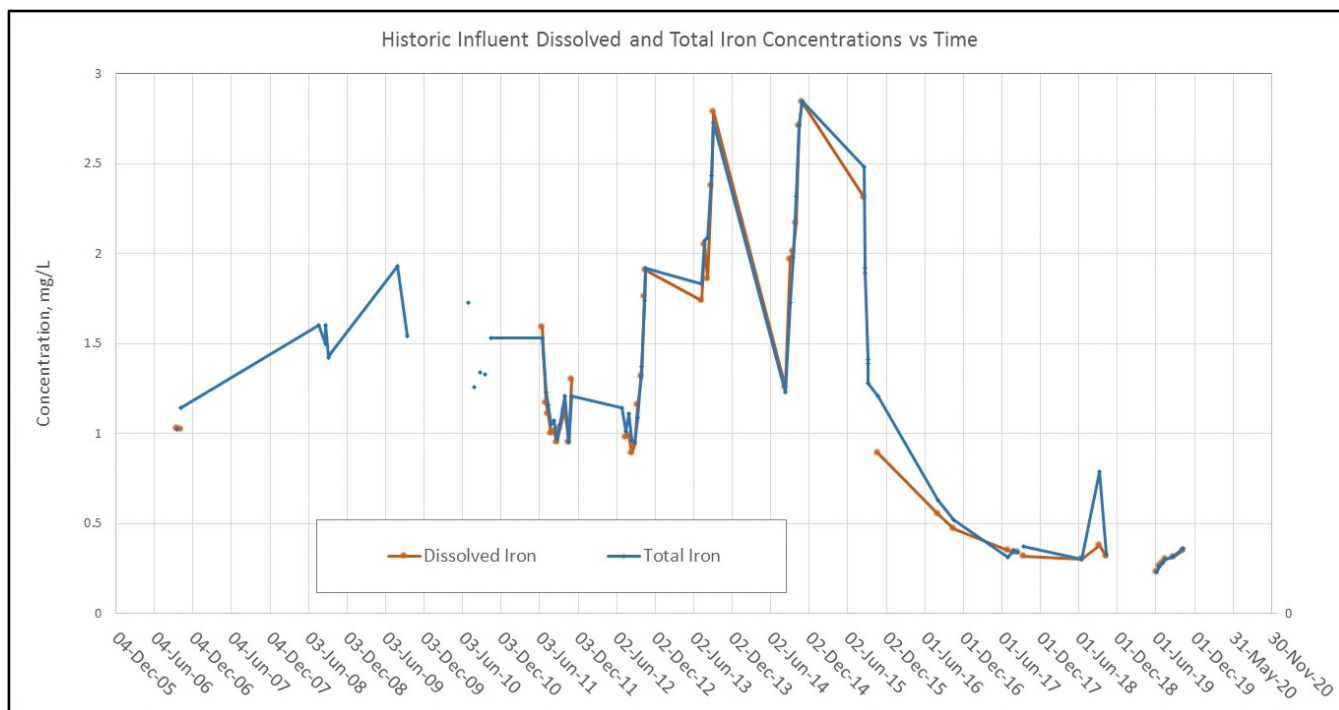
Raw Influent Water Samples	6/6/2019 Start-up	6/20/2019	7/1/2019	7/17/19	8/21/2019	10/7/2019 Shut-down
<b>Physical Properties</b>						
pH (S.U.)	7.7*					7.9*
Total Dissolved Solids (mg/L)	6950	6510	6660	6220	5930	8110
<b>Inorganics (mg/L)</b>						
Thiocyanate as N	4.1					0.69
Alkalinity, Total as CaCO <sub>3</sub>	220	200	210	220	220	210
Chloride	450	447	382	422	472	534
Sulfate	3780	4070	3720	3790	4270	4150
Cyanide, Total	0.5				0.78	0.6
Cyanide, Weak Acid Dissociable	0.004				0.094	0.004
Thiocyanate	1					2.8
Fluoride	0.4	0.4	0.4	0.4	0.3	0.4
<b>Nutrients (mg/L)</b>						
Nitrogen, Ammonia as N	15.3	14.2	14.6	15	17.4	19
Nitrogen Nitrate as N	<0.01	<0.01	<0.01	<0.01	<0.01	
Nitrogen, Nitrate+Nitrite as N	<0.01	<0.01	<0.01	<0.01	<0.01	<0.05
Nitrogen, Nitrite as N	<0.01	<0.01*	<0.01	<0.01	<0.01	0.02
Phosphorus, Total as P	0.08					0.1
<b>Metals, Dissolved (mg/L)</b>						
Calcium	513	510	512	478	497	527
Iron	0.23	0.26	0.28	0.3	0.31	0.35
Magnesium	65	64.2	58.6	56.6	62	74.6
Potassium	20	22	21	21	24	24
Sodium	1510	1510	1460	1510	1660	1820
<b>Metals, Total (mg/L)</b>						
Arsenic	0.197				0.241	0.258
Barium	0.027	0.027	0.026	0.027	0.030	0.035
Cadmium	0.00088				0.0006	0.00090
Copper	0.16				<0.01	<0.01
Iron	0.23	0.26	0.28	0.3	0.32	0.36
Manganese	0.542	0.59	0.59	0.56	0.58	0.62
Selenium	0.023				0.024	0.026
Silicon as SiO <sub>2</sub>	17	18	17.6	17.8	17.7	16.9
Silver	0.0005					<0.0005
Strontium	4.43	4.7	5	4.7	4.9	5.51

\* Analysis performed past recommended hold time

Constituents from the raw water samples were evaluated for concentration changes between the initial sample taken at the beginning of the treatment season and the end of year sample taken prior to system shutdown. Total cyanide increased slightly from 0.5 mg/L to 0.6 mg/L through the season; however, these values were lower than the minimum value observed the 2018 season despite leach pad solution levels being approximately the same. Weak Acid Dissociable (WAD) cyanide also exhibited lower concentrations during the 2019 season ranging from 0.004 mg/L to 0.094 mg/L. Thiocyanate concentrations however, increased over the treatment season from 1 mg/L to 2.8 mg/L, which is similar to values from previous seasons. Alkalinity levels remained stable at approximately 210 mg/L. Chloride level increased from 450 mg/L to 534 mg/L. Total Dissolved Solids (TDS) levels decreased throughout the first half of the season from 6,950 mg/L to 5,930 mg/L then rose sharply to 8,110 mg/L near the end of the season.

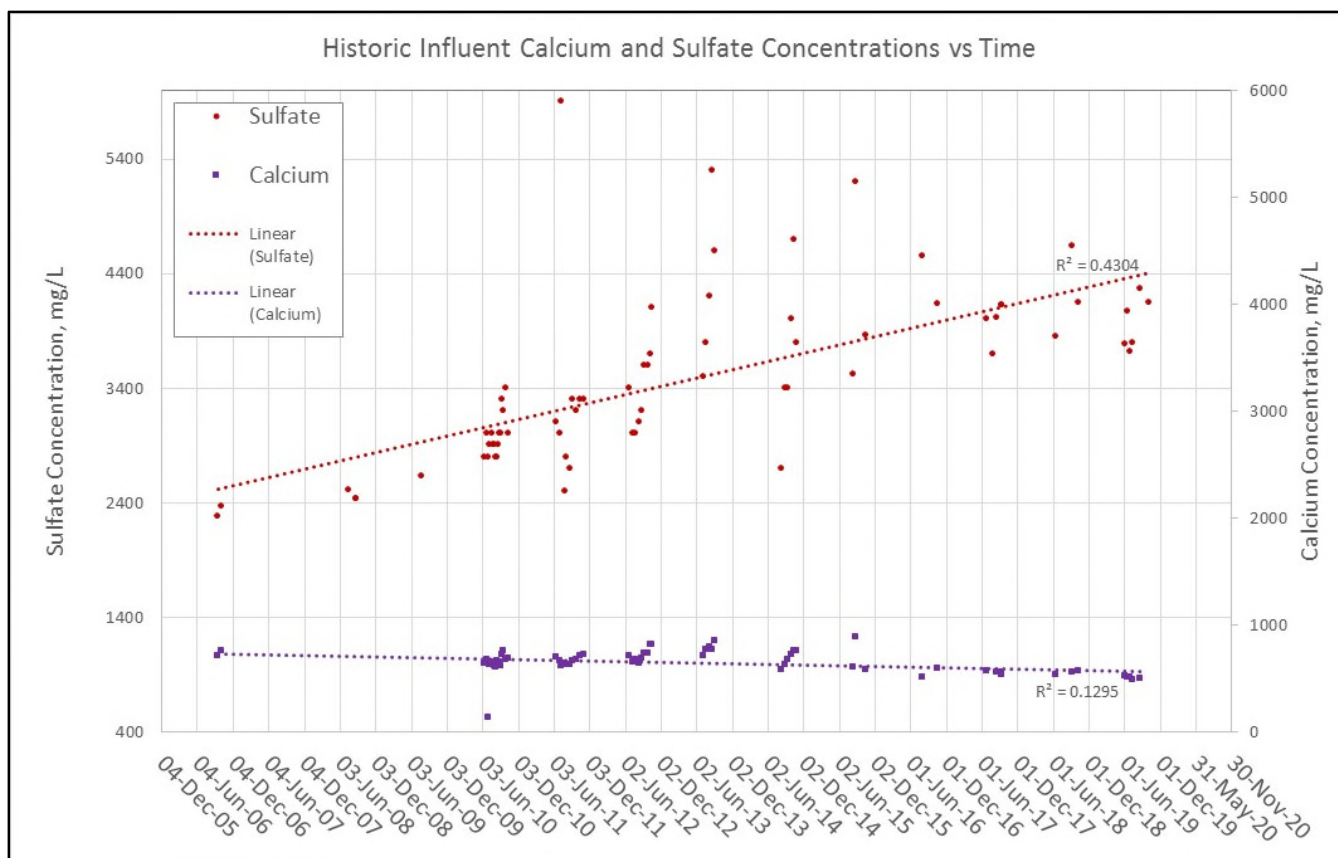
Nutrients remained relatively consistent throughout the treatment season with nitrates and nitrites below the method detection limit of 0.01 mg/L and ammonia ranging from 14.2 mg/L to 19 mg/L.

Dissolved calcium, iron, and magnesium varied slightly throughout the season but generally increased slightly by the end of the treatment season with values ranging from 513 mg/L to 527 mg/L, 0.23 mg/L to 0.35 mg/L and 65 to 64.6 mg/L, respectively. Dissolved sodium increased slightly from 1,510 mg/L to 1,820 mg/L. There were no significant changes in total metals concentrations analyzed over the 2019 treatment season.



**Figure 2. Dissolved and Total Iron Concentrations from 2011 to 2019**

Historic total and dissolved iron concentrations are shown in **Figure 2** above. The data indicates total and dissolved iron concentration values are nearly identical at varying magnitudes of concentration, indicating that most of the iron present in the leach pad is in dissolved form.



**Figure 3. Calcium and Sulfate Concentrations from 2006 to 2019**

Sulfate and Calcium concentrations were also generally consistent with the previous observations. Sulfate varied between 3,720 mg/L and 4,270 mg/L while calcium concentrations varied between 478 mg/L to 527 mg/L. 2018 concentration values for sulfate and calcium in raw water varied between 3,850 mg/L and 4,150 mg/L and 525 mg/L to 569, respectively.

**Figure 3** above illustrates an upward trend in sulfate concentrations of Beal RO raw water since 2006 while calcium concentrations, although with significantly less available data, appears to be trending slightly downward.

Compliance testing for the RO discharge to German Gulch was conducted under the Beal Site Wide Monitoring task. Sampling completed during June was conducted after RO system startup activities but prior to discharge activities and is representative of site conditions without treatment system discharge. During this period, ammonia was below the method detection limit while total cyanide and total recoverable selenium were slightly above their respective chronic aquatic life standards (MDEQ 2019). Selenium and cyanide documented for this period is not associated with treatment system discharge. Additional compliance testing was completed on September 16 during active treatment system discharge as part of Site Wide Monitoring. During this event, all constituents of concern were below chronic-aquatic life standards, and most were below method detection limits.

Laboratory analytic results of all samples collected as part of RO operations during the 2019 treatment season are attached in **Appendix A** and include performance samples associated with cleaning operations.

Results of raw water sampling suggest that leach pad water chemistry did not change significantly over the course of the treatment season.

## Field Tests

Water chemistry tests were performed throughout the 2019 treatment season utilizing field meters and field test kits (Hach®). Samples for field analyses were collected from four locations along the treatment flow path; INF-01 (raw influent water), INF-02 (Post Multi Media Filter (MMF)), 1<sup>st</sup> Stage Permeate (second stage feed), and 2<sup>nd</sup> Stage Permeate (final treated water). The results were recorded and used to analyze the system performance and implement any necessary adjustments to the treatment process. The four monitoring locations are arranged as follows:

- INF -01 (raw influent water) – This monitoring location is used to observe raw influent water pumped from the leach pad prior to being filtered through the MMF's;
- INF-02 (Post MMF) – Monitoring location after MMF's, but before 1<sup>st</sup> stage membrane arrays. Utilized to measure the effectiveness of the MMF's;
- 1<sup>st</sup> Stage Permeate – This monitoring point is on the low-pressure side of the 1<sup>st</sup> stage membrane arrays and before the water enters the 2<sup>nd</sup> stage membrane arrays of the RO system; and
- 2<sup>nd</sup> Stage Permeate – This monitoring point is on the low-pressure side of the final 2<sup>nd</sup> stage membrane array and represents treated water exiting the RO treatment system.

Influent (Raw Water) field conductivity ranged from a minimum of 7,500  $\mu\text{S}/\text{cm}$  on July 1<sup>st</sup>, after the system had been running for approximately 1 month, to its highest value of 9,330  $\mu\text{S}/\text{cm}$  on October 7<sup>th</sup>, resulting in an overall change of approximately 1,830  $\mu\text{S}/\text{cm}$  as compared to a 3,730  $\mu\text{S}/\text{cm}$  change observed during 2018 and 3,143  $\mu\text{S}/\text{cm}$  change observed during 2017.

2018 field-tested chlorine concentrations remained at or just above the method detection limit. Results of laboratory analysis for chlorine degradation by-products were below the method detection limits. Review of both the field and laboratory results suggests the field test kits may be biased high and that in fact chlorine is not present in the raw influent water at measurable concentrations.

## Membrane Cleaning

Prior to the start of the RO unit, several of the first pass membrane elements (first element of each vessel; 4 vessels per array; A, B, and C arrays in 1<sup>st</sup> pass) required cleaning due to observed debris lodged in the feed ends of the elements. The debris included small particulates of precipitated scale, sand-like particles, and other organic debris which had been observed during removal of the elements in the prior year. Membranes of the "B" and "C" arrays were installed just as they had been in 2018. The four (4) elements located at the feed side of the "A" array were reversed and placed in the back end of the vessels so that any debris dislodged would be removed with the waste stream during normal operations. The A and B arrays were then mechanically isolated by replacing the feed manifold which normally distributes feed waters to both arrays simultaneously (see Photo 1 below) with a single feed manifold (see Photo 2 below) and each array was then flushed with the CIP unit so that any debris dislodged would be captured by the CIP filter system.

### Feed Manifold A and B Arrays



Photo 1. RO A & B Arrays manifold feeding both arrays simultaneously.

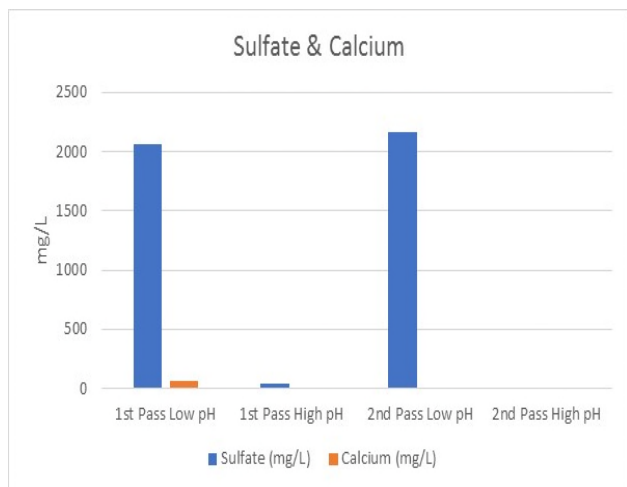


Photo 2. Single manifold placed to feed A or B array independently during cleaning operations.

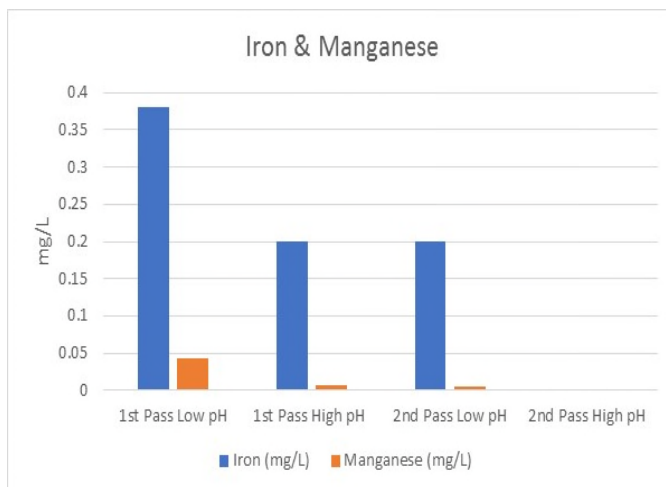
Tetra Tech conducted a mid-season cleaning of the RO membrane elements between July 31<sup>st</sup> and August 5<sup>th</sup>. Cleaning activities were initiated by pumping 2<sup>nd</sup> pass permeate water into each array of the 1<sup>st</sup> and 2<sup>nd</sup> passes of the RO system and allowing the system to soak overnight to loosen particulates and help dissolve precipitates. The CIP skid was then utilized to conduct a two-step chemical cleaning process of low pH solution followed by high pH solution. The first step utilized a cleaning solution of OptiClean™H and RO permeate water. OptiClean™H is a proprietary aggressive low pH, low foaming cleaner formulated to remove metal hydroxides, calcium carbonate, calcium phosphate and other inorganic scale. This product was chosen specifically to combat inorganic fouling that has traditionally been observed on the RO membrane elements and its ability to help reduce gypsum. Cleaning operations included mechanically isolating each array, pumping clean permeate water through each array at a targeted rate of 35-40 gallon per minute per membrane element with a maximum pressure of less than 60 psi. OptiClean™H was then mixed with permeate water in the CIP mixing tank to the concentrations recommended by the manufacture and the solution was recirculated through each array at the targeted rates stated above. Each array was then flushed with clean permeate water until the exiting solution was within 1 pH unit of the raw permeate water. The second cleaning step followed the same process but used a cleaning solution of OptiClean™B. OptiClean™B is a proprietary aggressive high pH, low foaming cleaner formulated to remove organic fouling. After the mid-season cleaning was completed, the system was allowed to soak in clean permeate for 48 hours prior to restarting.

An end of season cleaning of the membranes was performed between October 15<sup>th</sup> and October 18<sup>th</sup>. The cleaning entailed an initial system flush and soak with 2<sup>nd</sup> pass permeate water followed by use of the CIP Cleaning Skid with a low pH cleaner (OptiClean™H) as described above, followed by a thorough rinse with clean permeate water, then a high pH cleaner (OptiClean™B) as described above, followed by a thorough rinse with clean permeate water, and finally, a preserving solution consisting of 1% sodium metabisulfite (by weight) was pumped through the RO elements.

During both the mid-season and end of season cleaning events, samples were collected of the cleaning solution after flushing through the 1<sup>st</sup> pass and 2<sup>nd</sup> pass membranes. **Figure 4** and **Figure 5** below show the concentration of calcium, sulfates, iron and manganese after the cleaning solution was flushed through the membranes. The low pH cleaner seems to be effective at removing calcium and sulfate deposits as well as iron and manganese from the membranes. The high pH cleaner appears to be effective at removing additional iron from the membranes. Laboratory results are presented in Appendix A.



**Figure 4. Calcium and Sulfate Concentration in Cleaning Solution**



**Figure 5. Iron and Manganese Concentrations in Cleaning Solution**

## RO Membrane Maintenance

Tetra Tech conducted two scheduled soak periods as a preventative maintenance measure and three (3) unscheduled opportunistic soak periods during the 2019 operations. The first scheduled soak was completed June 22 through June 24 and the second scheduled soak was July 31 to August 1 just prior to the mid-season cleaning. Three extended soak periods were completed during unscheduled system down time presented in **Table 2** above. These periods included August 11 through August 15, August 27 through September 4, and September 25 through October 2, 2019. Because flow and pressure adjustments to the RO system are required following the soaking periods, improvements to RO membrane performance is difficult to identify when comparing before and after data. However, observations of system fluid conductivity following soaking periods have identified significant increases in SC values. Example: Clean 2<sup>nd</sup> pass RO permeate water (SC≈20 µS/cm) is pumped into the 1<sup>st</sup> pass vessels at low pressure. This process is identified as a “flush cycle” because the water is pushed through the membranes at low pressure not intended to generate permeate, therefore, the water flows through the membranes “flushing” the salts and contaminants from the membrane surface and pore spaces. This “flushing” process continues until the first stage discharge (reject flow) SC concentration is approximately equal to 300 µS/cm or less. The system is then allowed to soak for a minimum of 18 hours, and, upon re-initiation of a flush cycle, the 1<sup>st</sup> pass discharge waters now have SC values approximately equal to 1,500 µS/cm or more, 75-times greater than the water originally pumped into the 1<sup>st</sup> pass vessels.

The Beal RO system was not designed to allow a soaking period for the 2<sup>nd</sup> pass membranes as the quality of the water entering the 2<sup>nd</sup> pass was intended to be clean enough (<300 µS/cm) that soaking periods would not be necessary. However, the Beal RO system was designed with a “bypass valve” (valve YV125A) which was intended to allow minor amounts of raw water into the second pass feed stream if needed (such as system

startup) but generally allow excess 1<sup>st</sup> pass permeate to flow back into the 1<sup>st</sup> pass feed stream. In reality, valve YV125A allows raw untreated water (up to 60+ gpm) to flow into the 2<sup>nd</sup> pass feed stream which greatly increases 2<sup>nd</sup> pass feed constituent concentrations and pressures. The divergence from design is believed to be due to increases in raw water constituent chemistry, degradation of the media in the MMF's, and degradation of the 1<sup>st</sup> pass membrane elements. To combat the possible negative effects of this situation, Tetra Tech personnel pumped permeate water into each array of 2<sup>nd</sup> pass utilizing manual valve overrides during each soak event or periods of extended downtime.

At the end of the 2019 treatment season, the RO membrane elements were cleaned utilizing the CIP system (as discussed above), preserved with a 1% sodium metabisulfite (by weight) solution, and removed from the Beal RO system. Upon removal from the RO unit, each membrane was drained of excess solution, and a year-end inspection consisting of physical examination for signs of scaling or other damage of each membrane was performed. Each membrane was then placed in a new storage bag with both ends heat-sealed closed to protect the membrane element from drying out during storage. The 1% sodium metabisulfite solution is utilized to inhibit microbial growth during long term storage.

## RO Membrane Performance Normalization

Membrane performance in RO operations can be evaluated through a variety of data tracking and calculated parameters. Standard calculated parameters for RO systems in the industry often include differential pressures, net driving pressures, normalized permeate flows, salt passage or rejection, differential pressure drop coefficient, and permeability. Tetra Tech collected a variety of data throughout the 2019 operational season in order to calculate several of the parameters listed above. However, utilizing these parameters for membrane performance for the Beal RO system is difficult to evaluate in detail due to the following:

- Frequent system downtime – Beal RO system downtime, even for short periods of time, results in increased feed solution constituent concentrations (increased SC values) followed by a general downward trend in concentrations as exhibited in the 1<sup>st</sup> Pass Conductivity shown in Figure 1 above. Although these increases in SC are consistent in occurrence, they are not consistent in magnitude, duration, or the subsequent decrease. These observations are consistent with observations from previous years operations and is suspected to be the result of stratification of solution in the Beal leach pad and can result in data volatility.
- Operational adjustments – Operational adjustments to the Beal RO system are routinely performed to maintain appropriate flows and pressures and are often dictated by variations in the feed solution constituent concentrations. Adjustments of the Beal RO system can include feed water flow and pressure for 1<sup>st</sup> and 2<sup>nd</sup> passes, reject solution flow and pressure for 1<sup>st</sup> and 2<sup>nd</sup> passes, and leach pad well solution flow and pressure. Change to flow or pressure at any one of these locations can result in data volatility.
- Equipment calibration – Flow meters, SC meters, and pH meters require frequent checks and calibrations. Most calibration adjustments tend to be minor (less than 1% of display value) but those adjustments can skew data results.
- Variable feed solution constituent concentrations – Feed solution concentration to the RO system varies throughout the season. Decreases, as observed during early season operation, or increases in constituent concentrations due to down time or late season operations, trigger manual system adjustments to maintain appropriate flow and pressures in the system.
- Deteriorated condition of the 1<sup>st</sup> pass concentrate valve and 2<sup>nd</sup> pass feed valve.

Tetra Tech personnel collected specific data during the 2019 operational season to evaluate and optimize RO operations at the Beal Mountain site. The data collected included conductivity and pressure data for both feed and reject stream flows for each individual array of the RO system (1<sup>st</sup> Pass – 1<sup>st</sup> Array, 1<sup>st</sup> Pass – 2<sup>nd</sup> Array, 2<sup>nd</sup> Pass- 1<sup>st</sup> Array, 2<sup>nd</sup> Pass- 2<sup>nd</sup> Array, and 2<sup>nd</sup> Pass- 3<sup>rd</sup> Array). The data collected must then be “normalized” which is a technique used to evaluate if changes in flow or rejection are most likely caused by membrane fouling, membranes degradation, or just due to changes in operating conditions (Lenntech, 2001). The data can help to

determine cleaning regiments, chemical feed rates, and general system adjustments to help reduce the likelihood of creating conditions in the RO system which could lead to mass fouling of the elements.

Overall, the following system performance metrics suggest possible fouling of the 1<sup>st</sup> pass membranes during the early part of the season followed by improved performance latter in the season.

### Net Driving Pressure

The data collected was utilized to calculate Net Driving Pressure (NDP) which is essentially the sum of all forces acting on the membrane. These may include pump or feed pressure; back pressure from line restrictions and storage tank; and osmotic pressure of the feed and permeate waters. The net driving pressure is the measure of the actual driving pressure available to force the water through the membrane. As net driving pressure increases, the flux (permeate production) increases proportionally (given all other factors are held constant).

The average NDP<sub>a</sub> was calculated utilizing the following equation:

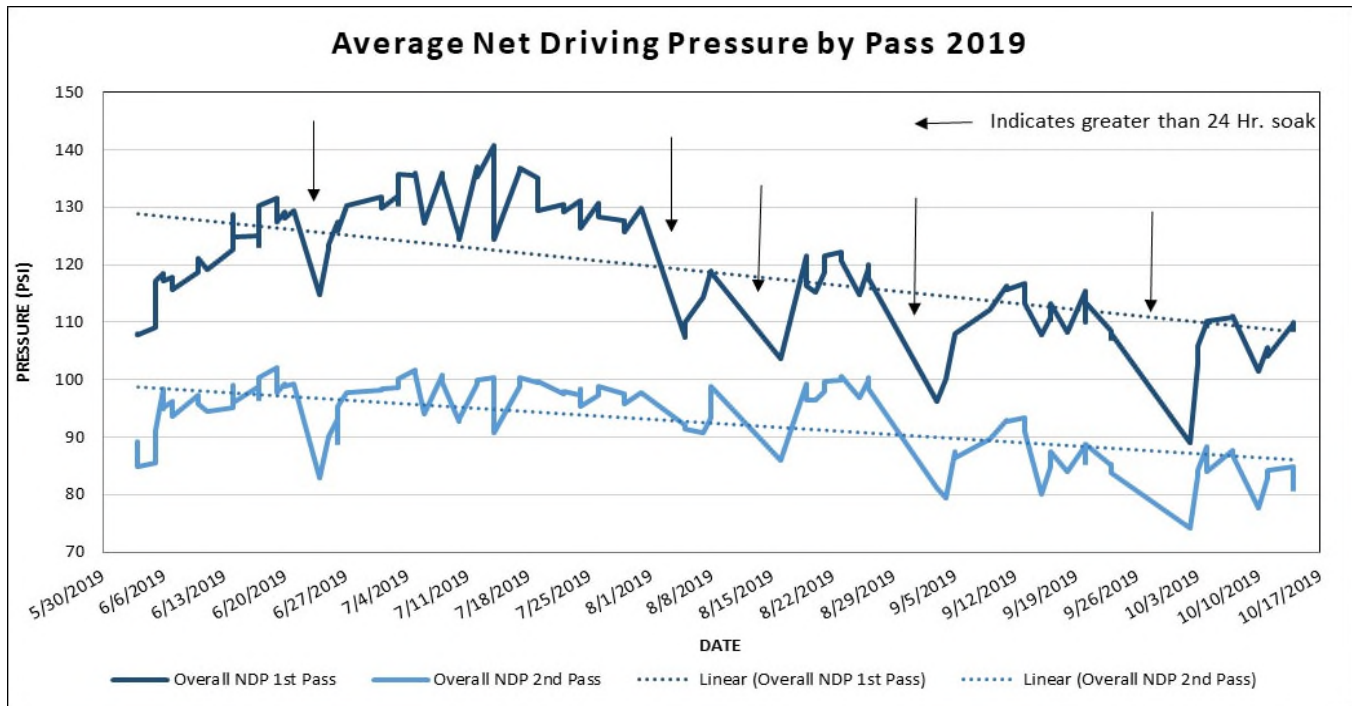
$$NDP_a = P_f - P_p - P_o$$

Where	NDP <sub>a</sub> = Average Net Driving Pressure
	P <sub>f</sub> = Average Feed Pressure (average of feed and concentrate pressures)
	P <sub>p</sub> = Pressure in the permeate line (gauge pressure)
	P <sub>o</sub> = Average Osmotic Back Pressure of feed water (average of feed and concentrate salt concentration divided by 100)

Generally, P<sub>o</sub> is calculated utilizing Total Dissolved Solids (TDS) values; however, for the Beal RO Plant this data is calculated utilizing the plant Specific Conductance (SC). This is done for convenience as plant in-process meters measure SC and because analysis of historic field data collected indicates that the relationship between SC and TDS is generally consistent.

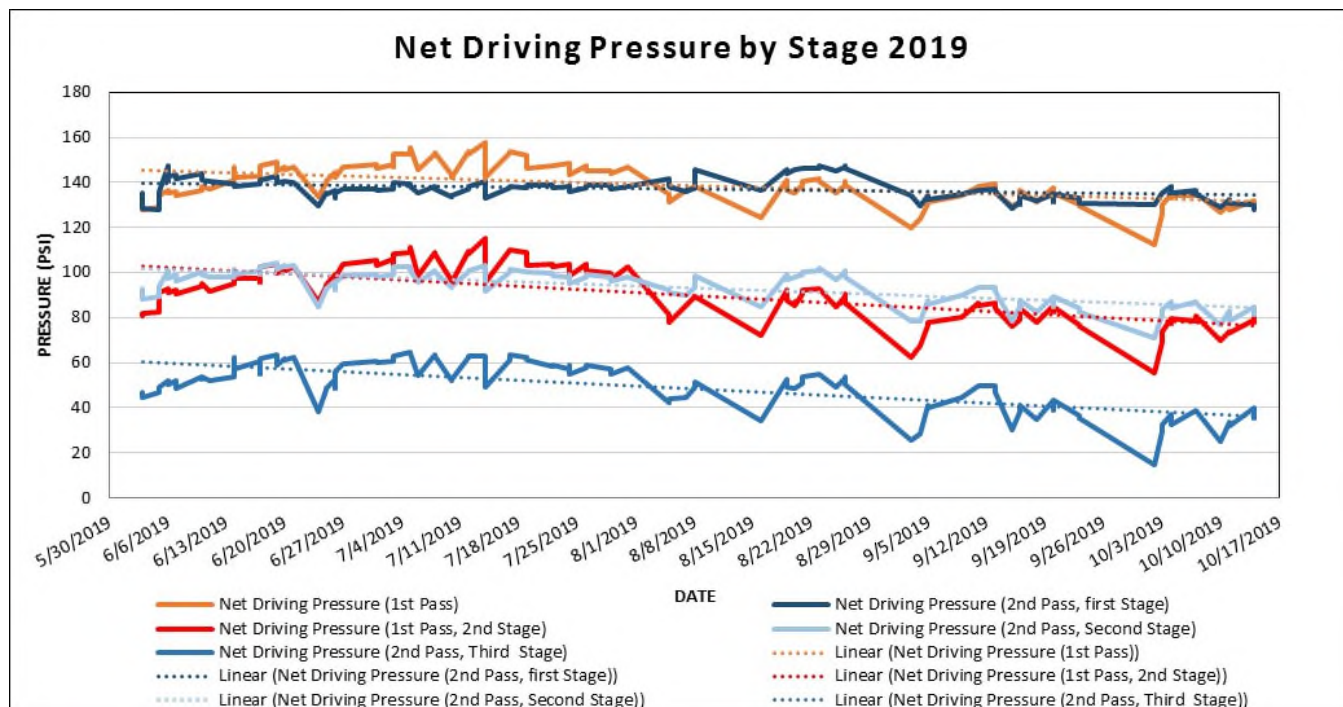
The NDP will begin to increase over time due to fouling or scaling of the RO membranes and it is common practice in the industry to instigate a membrane cleaning regiment when NDP increases by 15% to 25% above baseline value. Volatility and significant decreases in NDP can be due to variances in instrumentation (calibration of meters), errors made during data collection, significant system adjustments on nonautomated RO operations (such is the case a Beal), or influence from effective cleaning or soaking events.

When NDP is monitored for each stage of a RO system, problems can be identified between fouling and scaling based on the location of increases in pressure. An increase in NDP in the front stage of a RO indicates possible fouling issues while increases in NDP in a second stage indicates scaling. In general, average NDP increased over the first month of operation during the 2019 season then generally decreased during the second half of the operational season, ending at approximately the same value as at startup (**Figure 6**). **Figure 7**(below) displays NDP data for each array of the Beal RO system.



**Figure 6. Average Net Driving Pressure**

A slight overall increase in NDP would be expected in normal RO operations, particularly where systems are being operated near the upper limits of capacity for feed water chemistry, such as the case with the Beal RO system. The decreases in NDP throughout the second half of the season correlate with the mid-season cleaning (completed 08/05/2019) and the frequent system downtime which were used as soak events. It would appear that any fouling or scaling that may have occurred during the early season was removed by the midseason cleaning and that the frequent soak events resulted in minimal or no net accumulation of membrane fouling during the 2019 season. Additionally, the data tends to suggest that extended soaking periods can be nearly as effective as the cleaning events.



**Figure 7. Average Net Driving Pressure by Pass and Stage**

As stated above, evaluation of this type of data is complicated due to the everchanging feed water chemistry which results in continual system adjustments in order to maintain the appropriate flows and pressures. For most RO systems, feed water chemistry is generally consistent, so frequent system adjustments are not required which results in a much smoother graph.

Tetra Tech plans to continue the collection of RO data for the NDP calculation during future operations in order to develop better baseline data and the development of RO membrane cleaning protocols. Plant field data and the resulting calculated values for NDP are presented in **Appendix B** – Tables 1 and 2.

### Normalized Permeate Flow

The data was also utilized to calculate Normalized Permeate Flow (NPF) which is a comparison of RO permeate flow in the present operational conditions to the baseline permeate flow. The purpose of flow normalization is to account for variable input parameters such as net driving force and temperature, both of which have tremendous effect on permeate flows. The effect of these parameters is “normalized” to properly analyze the membrane performance.

Once NDP has been determined, NPF may be calculated based on NDP and temperature using the following equation:

$$NPF = \frac{(TCF \text{ today } ^\circ F) \times (NDP \text{ startup (PSI)}) \times (Permeate Flow (GPM))}{(NDP \text{ today (PSI)}) \times (TCF \text{ startup } ^\circ F)}$$

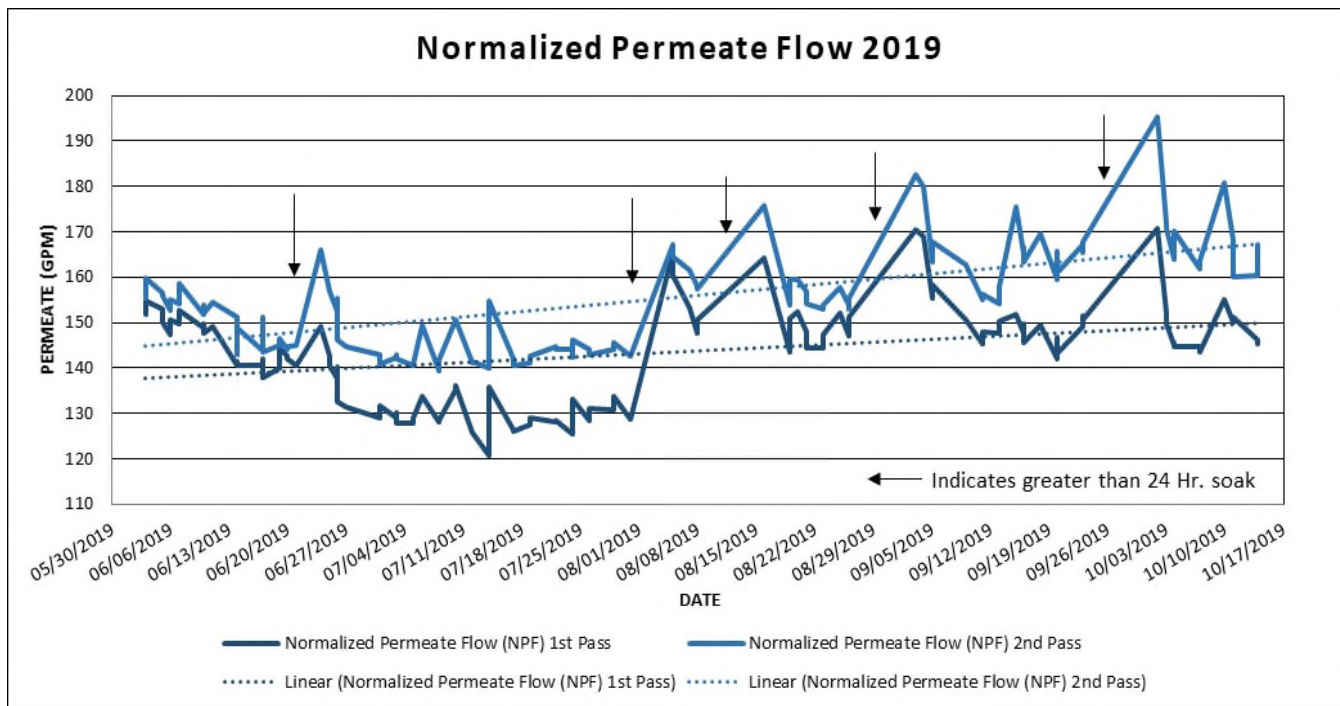
Where

NDP = Net Driving Pressure

NPF = Net Permeate Flow

TCF = Temperature Correction Factor (published values)

NPF measures the amount of permeate water that the RO is producing. A decrease in NPF could indicate that the membranes require cleaning while increases in NPF suggest either improved feed water quality (lower TDS), decreases in membrane foulant, possible leakage of brine seals or other membrane damage. NPF should always be evaluated with other operating parameters and take into account any system adjustments that also contribute to any NPF values. For instance, NPF increases combined with increased permeate conductivity may suggest brine seal leakage or membrane damage. In general, NPF in 1st and 2nd passes declined during the first month of operations, stabilizes during the second month, then increases through the remainder of the season (**Figure 8**). This suggests that during early season operations, fouling may have occurred. The removal of foulant during the mid-season cleaning combined with frequent soak periods associated with system down time resulted in improved system performance but still a slight net decrease in 1st pass membrane performance.



**Figure 8 Beal RO Normalized Permeate Flow**

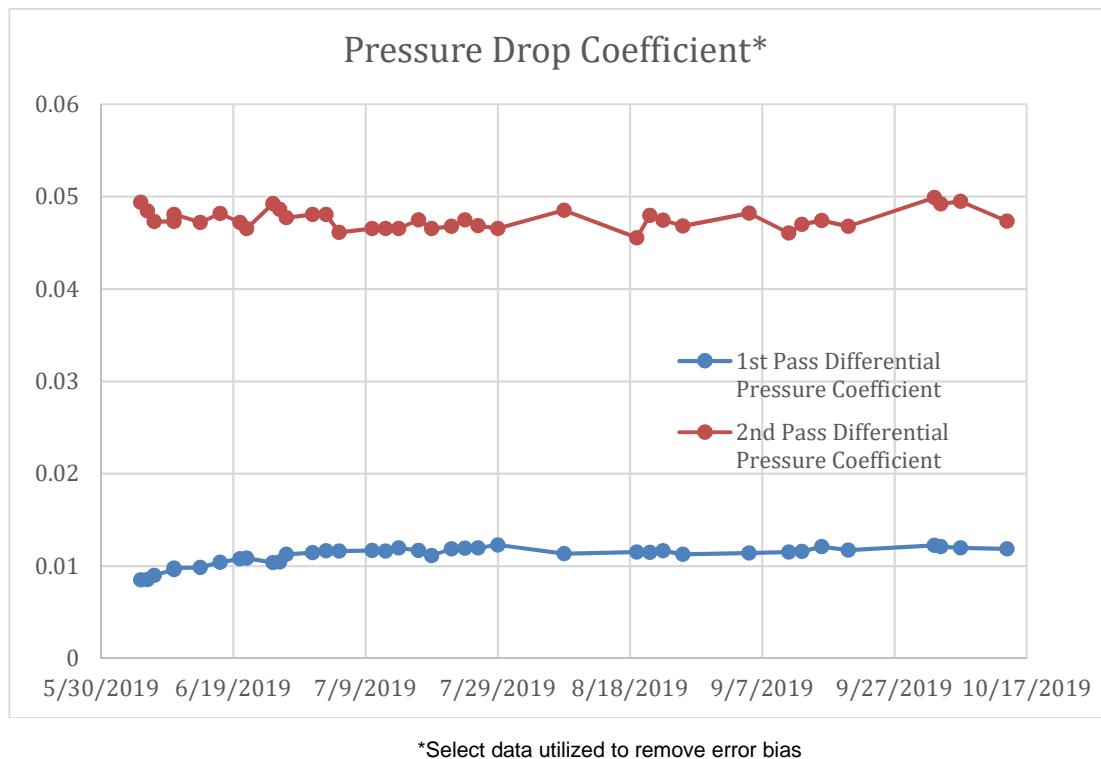
The data presented here is not definitive for several reason. The baseline for this data comparison was chosen as the season startup, which may contain significant bias. Second, the system was designed with a bypass line connecting first pass feed (raw water) and second pass feed (1<sup>st</sup> pass permeate) to help balance feed pressures to each booster pump. However, flows between the bypass line can vary significantly during operation which will alter the “normalization” of the data for second pass. Finally, system adjustments to operating pressures, flows, and permeate production will also impact the “normalization” values. When significant system adjustments were made, plant values were first recorded prior to those adjustments and then after to evaluate the effects of the adjustments on NDP and NPF. Plant field data and the resulting calculated values for NPF are presented in **Appendix B – Tables 1 and 2**.

### Differential Pressure Drop Coefficient

Differential pressure drop, is the difference between feed pressure and concentrate pressure, for a single array or pass. The Differential pressure drop coefficient attempts to normalize differential pressure for changes in flow.

$$\text{Pressure Drop Coefficient} = \frac{(\text{Pass Pressure Drop}(\text{psi}) \equiv [\text{Pass Feed Pressure} - \text{Pass Concentrate Pressure}])}{([\text{Pass Feed Flow}(\text{gpm}) + \text{Pass Concentrate Flow}(\text{gpm})]/2)^{1.5}}$$

In general, increases in the differential pressure drop coefficient are often used as an indicator of obstruction to flow (fouling) within the system. Foulant may be associated with particulates, biological growth, or dissolved solids precipitation (scale). Fluctuations in the coefficient can also be attributed to system adjustments, meter calibrations, feed and concentrate valve functionality, and system stabilization following shutdowns / restarts.



**Figure 9. Calculated Pressure Drop Coefficient**

Increases in the 1<sup>st</sup> pass differential pressure drop coefficient during the first month of operations supports possible membrane fouling followed by more stable performance; however, there were also significant system adjustments that occurred during the first few weeks of operation. The variability of 2<sup>nd</sup> pass coefficient values are likely due to operator adjustments to balance the system which resulted in fluctuations of the 2<sup>nd</sup> pass feed concentrations due to varying amounts of raw water passing through valve YV125A, instrument calibrations (flow meters and transducers), and issues associated with the deteriorating condition of the 2<sup>nd</sup> pass feed valve.

Tetra Tech plans to continue the collection of RO data for the differential pressure drop coefficient calculation during future operations in order to develop better baseline data and refine sampling protocols.

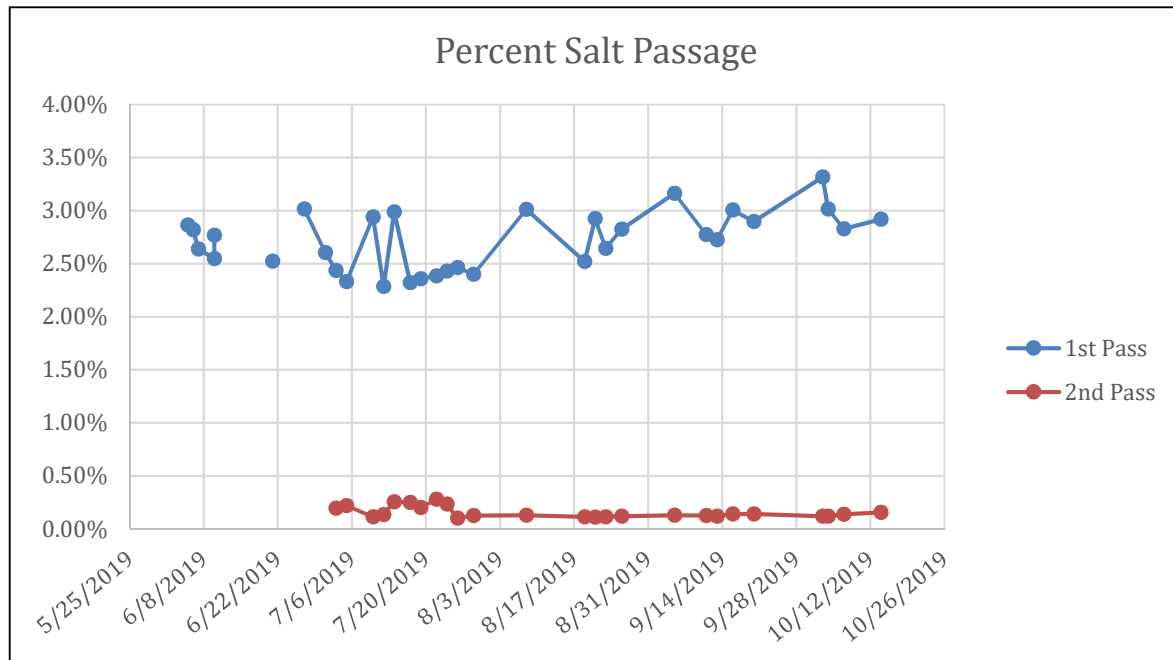
## Percent Salt Passage

Percent salt passage uses feed conductivity, concentrate conductivity, and permeate conductivity to evaluate membrane performance.

$$\% \text{ Salt Passage} = \frac{(\text{Pass Permeate Conductivity (SC)}) \times 2}{(\text{Pass Feed Conductivity (SC)} + \text{Pass Concentrate Conductivity (SC)})}$$

An increase in salt passage may be due to leaking brine seals, fouling, improper pH, high recovery rate, too high or low feed pressures, or changes in feed water chemistry. Initial evaluation of the relevant data collected during 2019 for this metric appears to suggest that 1<sup>st</sup> pass salt passage generally increases ( ) through the season and may suggest either membrane fouling/scaling or excessive operating feed pressure; however, significant system adjustments, instrument calibrations (SC meters), and operational constancy should be recognized as a significant contributor to the data variation. Second pass salt passage appeared to remain relatively stable throughout the season.

Tetra Tech plans to continue the collection of RO data for the percent salt passage calculation during future operations in order to develop better baseline data, evaluate membrane performance, and refine element cleaning protocols.



**Figure 10 Percent Salt Passage**

## Summary of RO Performance

Evaluation of the collective data for the RO during 2019 for net driving pressures, normalized permeate flows, salt passage, and differential pressure drop coefficient suggest the following:

- Mid-season cleaning was effective at removing early season fouling or scaling.
- Frequent extended soak events maybe nearly as effective as cleaning events resulting in minimal or no net fouling or scaling.
- The presence of the YV125A bypass and system adjustments to manage changes in feed chemistry must be considered when evaluating system performance metrics.

## Maintenance Tasks Completed During 2019

The RO system at Beal Mountain has completed its twelfth season of operation. Many of the system components are original equipment installs and due to their age, will have a higher probability for failure, especially when operating under the more strenuous conditions. Major maintenance projects completed in the 2019 operational season are listed below.

### Replacement of Second Pass Membranes

The 2018 Year 11 water treatment statement of work included a line item for the purchase and installation of 35 new second pass membranes. This work was not completed during the 2018 operable season; however, the replacement membranes were purchased under that statement of work. The replacement membranes were installed at the beginning of the 2019 operable season. During installation of the new membranes it was found that the new membranes have a smaller opening on the permeate port such that the membrane to vessel end cap adapter was not compatible. After a short delay, appropriate end cap adapters were obtained and installed without incident.

### Freshwater Pond Investigation

As part of the RO treatment process, permeate water is pumped from the RO Freshwater Storage tank to the freshwater pond located north of the RO building. The pond is utilized to provide the treated water additional exposure to air and sunlight in order to help reduce any residual ammonia (aeration of the water) or cyanide (hydrolyzed in sunlight). At the beginning of the 2018 operating season, a large tear in the Freshwater Ponds PVC liner was observed. Prior to contracting the repair of this liner further evaluation of liner integrity was deemed prudent.

The 2019 Year 12 water treatment statement of work included a line item for dewatering the Freshwater Pond with existing equipment in order to visually inspect the integrity of the synthetic liner. During the period of September and October 2019, the water level in the Freshwater Pond had been drawn down far enough to inspect and sample accessible sediments. Findings were as follows:

- Pond dimensions are approximately 250' x 250' x 50' deep with 1.75:1 slopes.
- The Liner material was compromised in multiple locations and consisted of rips, tears, and separated seams. Compromises were identified on all four pond slopes and at numerous elevations (i.e. above and below the typical water levels in the pond).
- Miscellaneous debris was observed at or near the bottom of the pond which included pipe, pipe fittings, and geotextile fabric.
- Sediment present was highly liquified with low cohesive strength.
- One shallow grab sample of sediment was obtained and submitted for laboratory analysis. Results indicate:
  - Non-detect for RCRA metals
  - Total Cyanide = 6.1 mg/kg
  - Weak acid dissociable cyanide = 0.5 mg/kg
  - Free cyanide =<4 mg/kg
  - Total Extractable Hydrocarbons = 988 mg/kg
    - <31 mg/kg C9-C18 Aliphatics
    - 321 mg/kg C19-C36 Aliphatics
    - 54 mg/kg C11-C22 Aromatics
  - 10.7% organic matter
- Total sediment depth estimated to be three feet but not confirmed. Therefore, sediment volume estimated to be 16,875 cubic feet (582 cubic yards).
- Chemistry of deeper sediments remains unknown.

### Beal RO Room Sump Disposal System

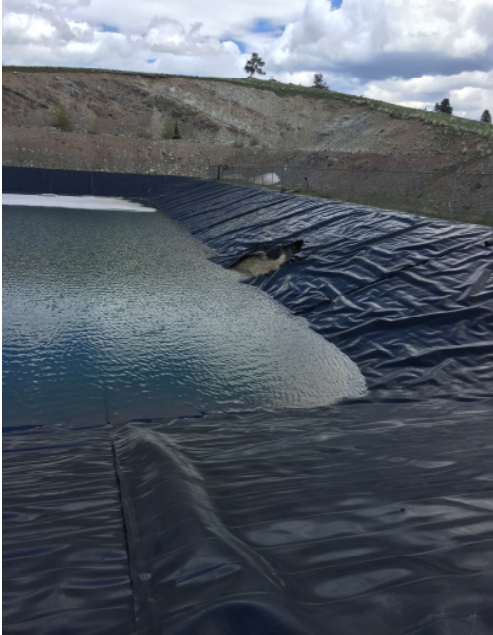


Photo 3. Tear in Freshwater Pond liner spring of 2018.



Photo 4. Freshwater Pond – September 2019.

### First pass reject valve replaced

Tetra Tech personnel purchased a replacement 1<sup>st</sup> pass reject valve and flanges which required custom welding and fabrication in order to fit the location. The original valve had been vibrating excessively during the past operating seasons and had become worn to the point that it is no longer functioning. The valve was fabricated and installed on August 2<sup>nd</sup> while the system is down for the mid-season membrane element cleaning.

### Second Pass feed valve replaced

Tetra Tech personnel purchased and replaced the 2<sup>nd</sup> pass feed valve on October 2<sup>nd</sup>, 2019. The valve, which was original to the system (2008), had become worn over time and began vibrating profusely shortly after startup during 2019 operations. Issues with the valve were most likely exasperated with the replacement of the 2<sup>nd</sup> pass membrane elements and system adjustments implemented to reduce the volume of raw water entering into the 2<sup>nd</sup> pass of the system.

### CIP heaters installed

Two heating elements and their related controls were installed in the CIP system on July 24<sup>th</sup>, 2019. The use of heated water for cleaning solution is recommended by the membrane manufacturers because it can be more effective and efficient at removing fouling. Installation included installing a temporary larger power supply cable to the Connex container and connecting heater controls to safety shutoff switches on the CIP.

### Freshwater Storage Tank pump impeller Replacement

On August 7<sup>th</sup>, the Beal RO unit experienced a system stoppage due to the failure of the impeller in the storage tank pump located immediately north of the Beal building. The pump and motor were removed and upon

inspection, it was discovered that the impeller had completely separated from the motor shaft adaptor. The cause of the damage was not discernable but may have been due to general fatigue as the pump and motor are original to the system (2008) or may have been caused from debris entering the pump from the storage tank as the tanks roof has degraded significantly in the past few years. Tetra Tech installed a temporary replacement pump which is undersized for this operation but continued to work throughout the season. Repair components were procured and installed during demobilization activities and the repaired pump will be installed prior to the 2020 operational season.

## **Exterior Lighting on South and West Building**

Additional LED outdoor lights were added to the exterior of the building during the 2019 operational year. One existing (partially functioning) light was replaced on the south side of the building and two (2) new units were installed on the west side to alleviate health and safety concerns associated with working at the site during dark hours.

## **RO PLC and SCADA Communication**

On August 11<sup>th</sup> at approximately 06:45, a significant electrical surge passed through the Programable Logic Controls (PLC) communications networks at both the RO Water Treatment Plant and at the extraction well located south of the plant. Tetra Tech personnel were notified of the plant shutdown via remote call system and traveled to the site to investigate. Upon arrival at the Beal Mountain site, severe thunderstorm activity was observed in the form of significant lightning, surface water runoff, and hail accumulations exceeding 6-inches. Initially, it was discovered that a pressure transducer located in the permeate water storage tank was not functioning (visible electrical scorching), PLC networks (three total) were not communicating, and the well Variable Frequency Drive (VFD) controller had faulted. Failed component replacement and system trouble shooting continued from August 11<sup>th</sup> through August 16<sup>th</sup> with help from our computer integration subcontractor Industrial System, Inc.

Industrial Systems is based in Vancouver, Washington but was able to remotely access the system to help identify faulty components and direct troubleshooting efforts. As damaged components were identified and replaced, it was discovered that additional components were either intermittently functioning or only partially functioning and needed repair or replacement. Finding replacement components was found to be especially challenging due to the “age” of the Beal RO unit. At 12-years in operation, the hardware platform of the PLC’s, Human Machine Interface (HMI), and communications systems are no longer manufactured or supported. The replacement components were procured through Industrial Systems and were generally remanufactured or factory certified used stock and were located through various vendors and suppliers. Additionally, most of the specialized hardware procured through Industrial Systems required programming that had to be completed through proprietary licensed software at their facility.

The system operated intermittently upon restart on August 16<sup>th</sup> through August 27<sup>th</sup> when the HMI unit stopped working altogether. Upon installation of a remanufactured HMI unit on September 4<sup>th</sup>, the system again ran intermittently through early October as various components were replaced and programming was altered to bypass problematic hardware. From August 12<sup>th</sup> through October 2<sup>nd</sup>, a period consisting of 53 days, the system was either non-operational or partially operational for 24 days and Tetra Tech personnel were onsite 30 days. During this time period, the following components were replaced/installed due to the electrical surge:

- Permeate Tank Pressure Transducer
- Upgraded communications transmitter for internet service
- Well PLC Input Module
- Main PLC Module
- VFD Pump Controller (swapped with onsite spare)
- HMI Unit
- Network Switches, Cables, and Router

- Main PLC Output Module
- Fiber Optic Network Module at Well and Plant
- Main PLC Module (Exchanged for warranty replacement)
- Allen-Bradley Power Supply
- Allen-Bradley Main PLC Chassis

The repair work following the lightning damage was extremely challenging due to the complexity of how the component failures manifested. The exact circumstances of the communication stoppages were rarely repeatable and generally were random. Following a repair, the system would often operate for a period of time (varying from hours to days) without incident but then would unexpectedly fault again. With each repair, it appeared the issues had been resolved, only to have a fault or communications failure cause the RO unit to shut down again. The work that Industrial Systems was conducting over the internet required Tetra Tech personnel to physically be onsite to monitor the system and perform physical tasks and testing needed to troubleshoot the system and complete the repair work.

## **System Maintenance Not Completed in 2019**

The 2019 Year 12 water treatment statement of work included a line item (Subtask 4C) for the replacement of RO system butterfly valves. This work was not completed in 2019 as it was deemed low priority when compared to unexpected costs associated with the August 11, 2019 lightning strike and subsequent communications issues.

## **Recommendations and Discussion**

Tetra Tech is making the following recommendations for future Beal RO water treatment plant operations:

### [Remove or Reconfigure Valve YV125A](#)

Tetra Tech recommends the removal or reprogramming of the “bypass” valve identified as YV125A. The purpose for the valve in the originally designed system was to return a portion of the 1st pass permeate back into 1st pass feed, which reduces influent contaminant concentrations and helps balance feed pressures between 1st and 2nd pass arrays.

Thirteen years of operating the RO system has resulted in higher contaminant concentrations in the leach pad influent. The degrading water quality has reduced the RO system capacity and has resulted in an opposite flow path through the YV125A valve (raw water is now being pushed through the valve into the 2nd pass feed waters). The problem was further exacerbated in 2019 when the 2nd pass membrane elements were replaced and the aging 1st pass elements were not able to supply adequate water to the 2nd pass of the system. This condition will shorten the life of the newly purchased second pass membranes and increase the possibility of a mass precipitation event in the 1st pass of the system, especially if the system is operated at higher production levels.

YV125A valve replacement will require rebuilding significant portions of the 1<sup>st</sup> and 2<sup>nd</sup> pass feed plumbing and will also require a new Variable Frequency Drive (VFD) controller for the 2<sup>nd</sup> pass booster pump. Alterations to the system PLC/SCADA programming will also be necessary. Tetra Tech is currently in the process of identifying the available options and costing where possible.

### [Replace First Pass Membrane Elements](#)

The 1<sup>st</sup> pass consists of 2-stages; stage 1 includes the “A” and “B” Arrays with 4 vessels in each array containing 6 elements per vessel for a total of 48 membrane elements, and stage 2 consists of the “C” Array with 4 vessels containing 6 elements per vessel for a total of 24 membrane elements. In 2009, all 24 of the “C” array membranes were replaced due to significant scaling. In 2012, all 72 of arrays “A”, “B” and “C” membrane elements were replaced due to with severe scaling, and in 2015, 27 membrane elements were replaced in Arrays “A” and “B” in various locations due to significantly higher than average element weights.

Tetra Tech recommends the replacement of all 72 1<sup>st</sup> pass RO membrane elements in order to maximize the production of 2<sup>nd</sup> pass permeate water, reduce the level of solution in the Beal heap leach pad, extend the life of the new (2019) 2<sup>nd</sup> pass membrane elements, and provide a new operational baseline (point of comparison for operational adjustments) reflective of the current raw water conditions.

#### [Replace Media in MMF Vessels 100, 200, and 300](#)

The media material in the Multi Media Filters (MMF's) has not been changed since the construction of the RO system in 2008. The media consists of a gravel layer which covers the underbed plumbing, a 3-inch thick garnet sand layer, a 24-inch thick greensand layer, and a 12-inch thick anthracite layer. Testing of the media in 2016 identified that the greensands are no longer functioning, and that pretreatment media has generally degraded in size which reduces flow capacity, filtering efficiency, and backwash effectiveness through the media.

Tetra Tech RO experts have reviewed laboratory and operational data from the past few operational seasons and have concluded that the greensand media is no longer needed in the MMF configuration due to the Total Iron, Ferrous Iron, and Manganese complexation with cyanides.

Tetra Tech recommends replacing the original media with different products that will provide greater filtering capacity and increased flow capacity. This is especially important because replacement of the 1<sup>st</sup> pass membrane elements and removal of the bypass valve YV125A will necessitate maximum 1<sup>st</sup> pass production which in turn requires achieving the original design raw water feed flow through the MMF's.

#### [Replace RO SCADA Computer and Upgrade Software](#)

Tetra Tech recommends the replacement of the SCADA computer and associated system software. The current computer uses Microsoft Windows 7. During 2019, Microsoft reduced support for Windows 7 and will completely discontinue support in June of 2020. The Microsoft action has led other windows-based software manufactures, such as the WonderWare used by the SCADA program and the Rockwell software utilized by the Human Machine Interface (HMI), to stop support of their software versions for the Windows 7 operating system as well. In addition, the Beal RO SCADA computer has operated in extremely challenging conditions including dirty/dusty air, high humidity, and several plumbing failure events which resulted in complete saturation of the machine. These conditions have resulted in unstable computer operations and increased potential for cyber-attack.

#### [Mid and End of Season Cleanings](#)

Routine RO membrane maintenance is required to optimize the life span of membrane elements, deliver efficient RO operation, and minimize system pressures which will prolong the life of other system components such as pumps and valves. Membrane maintenance includes the practice of "soaking" elements, permeate rinses with CIP, and chemical cleaning. Historically, the Beal RO elements received an end-of-year cleaning and occasionally, when production rates were high, a mid-season cleaning as well. Due to the concentration of contaminants in the solution being treated at the Beal RO water treatment plant, Tetra Tech strongly recommends membrane elements undergo periodic permeate soak events along with a mid and post season cleaning. The midseason cleaning will be utilized to remove accumulated foulants which will maximize membrane life, membrane operational efficiencies, and reduce operational pressures. Every RO system is different and faces a unique cocktail of constituents to remove during the cleaning process, making an exact protocol for chemical usage and cleaning procedure impossible to generically template. However, Tetra Tech continues to identify and develop procedures which are tailored to the Beal site since the CIP purchase in 2017.

The post season cleaning should include the additional step of membrane preservation by pumping a 1% sodium metabisulfite (by weight) solution through the system which is required for proper storage of the membrane elements.

### *Dedicated CIP Equipment Area*

Tetra Tech recommends the construction of a dedicated area within the existing RO building for operation and storage of the CIP system. This approach would greatly reduce hazards (Slips, Trips, and Falls) created by hoses connecting the CIP (currently in Connex storage container) and the RO system as well as hazards associated with ice formation on walking surfaces during cleaning operations conducted during the latter portions of the season. Additionally, relocation of the CIP system would allow for safe working space when adding chemicals to the CIP system.

### *Remove Permeate Storage Tank Cover and Clean Tank*

2<sup>nd</sup> pass permeate water from the RO system is transferred into a large steel Freshwater Storage tank located just north of the RO building. The tank was originally part of the Beal Mountain Mine operation and was incorporated into the RO operations to provide surge and storage capacity for RO operations including the ability to provide water for membrane flushing and cleaning operations, both of which require extremely clean water (i.e. 2<sup>nd</sup> pass permeate) in order to be efficient and prevent further damage to the membrane elements.

During mine operations, an insulated ceiling was installed on the tank which consisted of placing sheet Styrofoam and oriented strand board (OSB) over openings at the top of the tank. The OSB is now degraded and large pieces have been blown off or fallen into the tank from the roof. The debris in the tank can be problematic because it can block the transfer pump outlet and fouls the permeate water needed during membrane maintenance activities.

Tetra Tech recommends removing the remaining roofing material. Additionally, Tetra Tech recommends accessing the tank interior and pressure washing the lower portions of the tank to remove debris.

### *RO System Butterfly Valve Replacement*

Tetra Tech recommends that butterfly valves in the RO system be replaced prior to the start of the system in 2020. The valves are an important component in the RO system and utilized to divert process waters within the system when in operation as well as isolate portions of the system during various cycles of RO operations. All of these valves are original to the system and have reached the end of their operational expectancy. At least two of the valves were identified as allowing fluid to pass while in the closed position while performing system check valve inspections and replacement activities in 2018.

### *Freshwater Pond Level*

Results of the 2019 investigation identified numerous compromises in the liner material of the Freshwater Pond. Tetra Tech recommends the Upper Pond be kept as low as operationally possible during the 2020 water treatment season to minimize the quantity of water that may be entering the groundwater system in that area.

## REFERENCES

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## APPENDIX A – WATER LABORATORY ANALYSIS

## APPENDIX B – 2019 OPERATIONAL FIELD DATA

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**To:** Sonny Thornborrow, US Forest Service

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**From:** Randal English

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**Date:** May 28, 2020

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**Subject:** Yearly Operations Summary – 2019 Beal Year 12 RO Treatment Season

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**Contract:** GS-00F-168CA (Order 12034319F0152)

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Tetra Tech is pleased to submit this Yearly Operations Summary – 2019 Reverse Osmosis (RO) Year 12 Water Treatment Season for the Beal Mountain Mine located 16 miles west southwest of Butte, Montana, in Silver Bow County. This yearly report is required as a deliverable for Task 6 of the Beal Mountain Mine Year 12 Work Order. Data reported includes water volumes treated through the RO Treatment System, heap leach solution level monitoring, and heap leach laboratory and field solution chemistry analytical results.

### **TOTAL LEACH PAD SOLUTION VOLUME TREATED BY RO**

The Beal RO Water Treatment system activities began May 3, 2019 with the restoration of power to the site following snow removal. On May 14<sup>th</sup> Tetra Tech mobilized to the site and began assembling the RO plant and began circulating from the extraction sump (Sump-1) to the reject sump (Sump-3A) in order to clean any accumulated scale from the pipes and begin blending the stratified (presumably) leach pad solution. Full mobilization efforts began on May 17, 2019, with the mobilization of membranes to the site and subsequent plant assembly. The RO system was started on May 30, 2019, and full-scale water treatment began on May 31<sup>st</sup> following minor system repairs. Minor system repairs included pressure gauge checks, pressure transducer calibration, meter calibration, and addressing a non-functioning transducer on the Fresh Water Storage Tank.

At startup, the water treatment totalizer meter reading was reset to zero (0) gallons. The Year 12 contract called for the RO System to produce 18 million gallons of treated water. A contract modification (Mod #1 dated August 28, 2019) authorized the production of an additional 4 million gallons of treated water. The treatment season ended October 14, 2019, with the plant 2<sup>nd</sup> pass permeate (treated water) meter reading 22,006,682 gallons. This is the actual treatment volume for the Year 12 water treatment season. Total treated water produced to date is 234,932,106 gallons.

Heap leach solution elevation in Sump 1 was measured on May 9<sup>th</sup>, 2019 at 7491.45 feet; the solution elevation at the end of the treatment season on October 14<sup>th</sup>, 2019 was 7,482.26 feet.

### **BEAL RO SYSTEM OPERATIONS**

The multi-stage, semi-permeable membranes are the primary contaminant removal component of the Beal Mountain RO system. A membrane functions when influent water is supplied to the membrane surface at a pressure greater than the osmotic pressure of the solution being treated. This creates a significant pressure differential across the membrane, forcing water molecules through the membrane. The pore size on the membranes restrict the passage of impurities, bacterium, and ions larger in size than the pores of the membrane. The solution that passes the membranes is called “permeate”, the remaining solution is referred to as “reject”.

The concentration of contaminants in the solution being treated dictates the operating pressure on the membranes. A higher contaminant load requires higher operating pressure due to the higher osmotic pressure exerted by the water and the dissolved solutes. When operating at elevated pressures, the system must be closely monitored to avoid damaging the membranes. Damage can occur when excessive pressure is applied to the membranes and the differential pressure between the feed side and the permeate side becomes too high, so that ions are forced into the membrane pores or the reject water becomes so highly concentrated that it can no longer keep the ions and molecules suspended in solution resulting in precipitate formation. This precipitation forms solid molecules and is often referred to as membrane “scaling” or “fouling”. Significant scaling greatly reduces the operational capacity of a membrane element, as well as the overall life cycle of a membrane. Meticulous attention must be paid to operational parameters and diligent system adjustments must be made to prevent catastrophic scaling from occurring when operating RO systems near the upper limits of their design capacities, such as the scenario at the Beal RO plant. To operate at the upper limits of design, the amount of permeate needs to be reduced in order to keep solution concentrations in the reject below the point of mass precipitation.

Regular membrane cleaning regiments can be employed to remove minor amounts of scale and fouling. One of the membrane cleaning options include “soaking” the RO membranes (1<sup>st</sup> Pass, 2<sup>nd</sup> Pass, or Both) in 2<sup>nd</sup> pass permeate water (treated water). This process involves pumping stored 2<sup>nd</sup> pass permeate water into the membrane vessels while monitoring the Specific Conductance (SC) of the reject water. Permeate water is pumped into the vessels until the SC measurements of the reject water from those vessels are observed to be at or near the SC values of the water being pumped in. The membrane elements are then allowed to soak in the clean water for approximately 18 to 24 hours. This allows salts and other dissolvable constituents, along with micro fine particulates, to be removed from the membrane surfaces and pore spaces, improving membrane efficiency and reducing the probability of a mass scaling event to occur. The practice of “soaking” the membranes is widely accepted amongst water treatment professionals and is highly recommended by Tetra Tech’s RO experts who are familiar with the current RO configuration and have evaluated the chemical constituents of the Beal RO raw water. Another membrane cleaning option utilizes specially formulated chemicals of low pH (2 – 3) and high pH (10 - 11) mixed in solution. The solutions are then pumped and recirculated through each array of the system at a targeted flow and pressure which allows the solution to scour out precipitates and fouling. Both cleaning regiments were employed during the 2019 water treatment season and are further discussed under section Membrane Cleaning below.

## **Beal RO System Operational Efficiencies**

The volume of treated water was monitored and recorded using the Beal RO system computer software data logger. Tetra Tech has calculated an estimated net effective efficiency for the 2019 RO operations by extracting flow data from the RO influent and 2<sup>nd</sup> pass permeate lines (total gallons solution in and total gallons 2<sup>nd</sup> pass permeate out). The data set consisted of extracting flow meter readings (gpm), at sixty-minute intervals, from archived computer data. The entire 2019 treatment season’s influent and 2<sup>nd</sup> pass permeate flow data was then averaged and divided to produce a single estimate of the efficiency at which the RO treats heap leach pad water. In 2019, it is estimated that for every gallon of water entering the RO system, 0.47 gallons of water was produced as 2<sup>nd</sup> pass permeate, as compared to 0.44 gallons in 2018 and 0.39 gallons in 2017. The values calculated are to be considered as estimates because this method does not account for situations where influent water is not fully processed to produce permeate such as while backwashing the Multi Media Filters (MMF’s) or during startup cycles prior to the system coming fully online. The treatment volumes for years 2008 – 2019 are summarized below in **Table 1**.

**Table 1. 2019 Yearly RO Total Treated Water (2nd pass permeate) Summary**

Year	<sup>1</sup> Total Days	Total Gallons Treated (2 <sup>nd</sup> pass permeate)	Average Treatment Rate (gpd 2 <sup>nd</sup> pass permeate)	<sup>2</sup> Approximate Net Effective Efficiency (%)
2008	61	12,007,550	196,845	45%
2009*	119	25,377,606	213,257	46%
2010	130	33,638,532	258,758	44%
2011	147	32,136,432	218,615	46%
2012*	119	24,959,896	209,747	48%
2013	79	13,881,032	175,709	46%
2014	86	14,712,416	171,075	46%
2015*	64	11,295,392	176,491	45%
2016	73	13,188,800	180,668	44%
2017	84	13,500,660	160,722	39%
2018	110	18,227,100	165,701	45%
2019*	98	22,006,682	224,558	47%

\* Indicates year where membranes were replaced. (24 in 2009; 87 in 2012; 27 in 2015; 35 in 2019)

<sup>1</sup> Days of operation were estimated utilizing archive data from RO computer. Total excludes scheduled maintenance including RO membrane soaking periods.

<sup>2</sup> Based on archive data from Beal RO computer. Data is considered estimated due to being derived from season-long averages of flow streams.

Average 2<sup>nd</sup> pass permeate production rates increased significantly in 2019 with an average daily production rate of 224,558 gallons 2<sup>nd</sup> pass permeate produced. Historic average daily production rates range from 160,722 gallons per day in 2017 to 258,758 gallons per day in 2010. Average 2<sup>nd</sup> pass permeate rates were calculated by dividing the total 2019 2<sup>nd</sup> pass permeate production by the estimated number of full days the plant was in operation, not counting downtime during MMF backwashes or down time during maintenance activities. These production rates should be considered approximate.

The Beal RO system was originally designed for 66% permeate extraction (maximum) through the first pass of the system. That 1<sup>st</sup> pass permeate (66% of original raw) is then sent to the 2<sup>nd</sup> pass of the system where it was designed to extract 90% permeate (maximum) (90% of the 1<sup>st</sup> pass permeate), resulting in a maximum possible net efficiency of 59.4%. This was based on the data collected during the RO pilot project conducted in 2006. The Beal RO water treatment system is currently being operated with 50 – 60% permeate extraction in first pass followed by 60 – 70% permeate extraction in second pass to keep the system pressures at a safe level, prevent equipment damage, and avoid potential scaling. The primary driver for the reduction in the 2<sup>nd</sup> pass recovery is the reverse flow condition present at the YV125A bypass valve. The purpose for the valve in the originally designed system was to return a portion of the 1<sup>st</sup> pass permeate back into 1<sup>st</sup> pass feed, which reduces influent contaminant concentrations and helps balance feed pressures between 1<sup>st</sup> and 2<sup>nd</sup> pass arrays. Thirteen years of operating the RO system has resulted in higher contaminant concentrations in the leach pad influent. The degrading water quality has reduced the RO system capacity and has resulted in an opposite flow path through the YV125A valve. Raw water is now being pushed through the valve into the 2<sup>nd</sup> pass feed waters which

degrades the 1<sup>st</sup> pass permeate water quality. This results in the Beal RO system being operated between 43% and 51% net efficiency. The data presented in **Table 1** above was derived through collecting “snapshots” (once every sixty minutes) of flow rates and averaging them into a single number; therefore, it is an approximation which does not account for system operational variability.

## Beal RO System Operational Availability

The RO system availability is summarized in **Table 2** and is further described below.

**Table 2. RO Treatment System Availability Summary**

Date	Cause of Shutdown	Duration
06/11/2019	Low Power Quality	~ 0.2 Day
06/22/2019 – 06/24/2019	System shutdown for membrane soak	~ 3 Days
07/06/2019	Low Power Quality	~ 0.75 Day
07/09/2019 – 07/10/2019	Low Power Quality	~ 1 Day
07/13/2019 – 07/14/2019	Low Power Quality – T-storm	~ 1 Day
07/31/2019 – 08/05/2019	Membrane soak and Mid-Season Cleaning	~ 5 Days
08/07/2019	RO Surge Tank Pump Impeller	~ 0.5 Day
08/11/2019 – 08/15/2019	Low Power Quality – lightning strike; multiple communication losses and Programmable Logic Controller (PLC) faults; membrane soak while system down	~ 5 Days
08/19/2019	PLC/Supervisory Control and Data Acquisition (SCADA) Communication issues	~ 0.25 Day
08/20/2019	PLC/SCADA Communication issues	~ 0.25 Day
08/25/2019	PLC/SCADA Communication issues	~ 0.25 Day
08/27/2019 – 09/04/2019	PLC/SCADA Communication issues; membrane soak while system down	~ 8 Days
09/09/2019	PLC/SCADA Communication issues	~ 0.5 Day
09/14/2019 – 09/15/2019	PLC/SCADA Communication issues	~ 1.5 Day
09/17/2019 – 09/18/2019	PLC/SCADA Communication issues	~ 0.75 Day
09/23/2019	Low Power Quality	~ 0.2 Day

09/25/2019 – 10/02/2019	PLC/SCADA Communication issues; membrane soak while system down	~ 7.75 Day
10/09/2019 – 10/10/2019	PLC/SCADA Communication issues and frozen pipes	~ 1.75 Days

During the 2019 treatment season, there were numerous unanticipated shutdowns of the RO system due to power quality issues, PLC communications issues (following lightning strike), and mechanical failures.

#### **1<sup>st</sup> Shutdown – Low Power Quality**

Tetra Tech arrived on-site on June 11<sup>th</sup> following notification from the RO system that the unit was down. It was determined that the system shutdown was caused by a “Low Power Quality” fault likely due to a power bump rather than full loss of power.

#### **2<sup>nd</sup> Shutdown – Operator initiated Shutdown for Membrane Soak**

The RO system was intentionally shut down on June 21<sup>st</sup> for a 48-hour membrane soak. Second pass permeate was pumped through 1<sup>st</sup> pass (both stages) and 2<sup>nd</sup> pass (all 3 stages) utilizing the clean in place (CIP) system at the flow and pressure recommended by the element manufacturer. The system was restarted June 24<sup>th</sup>.

#### **3<sup>rd</sup> Shutdown – Low Power Quality**

Tetra Tech arrived on-site on July 6<sup>th</sup> following notification from the RO system that the unit was down. It was determined that the system shutdown was caused by a “Low Power Quality”, low voltage fault at the RO plant and a well fault on the frequency drive at the well head, which was most likely due to a brief systemwide power loss. The system was restarted on July 6<sup>th</sup>.

#### **4<sup>th</sup> Shutdown – Low Power Quality**

Tetra Tech arrived on-site on July 10<sup>th</sup> following notification from the RO system that the unit was down. It was determined that the system shutdown was caused by a “Low Power Quality”, power failure. The system was restarted on July 10<sup>th</sup>.

#### **5<sup>th</sup> Shutdown – Low Power Quality**

Tetra Tech arrived on-site on July 14<sup>th</sup> following notification from the RO system that the unit was down. It was determined that the system shutdown was caused by a “Low Power Quality” fault likely due to a power bump rather than full loss of power. The sensitivity of the power sensor was slightly reduced, and the system was restarted.

#### **6<sup>th</sup> Shutdown – Operator initiated Shutdown for Membrane Soak and Mid-Season Cleaning**

The RO system was intentionally shut down on July 31<sup>st</sup> for a 24-hour membrane soak prior to the start of the mid-season cleaning. The precleaning soak was utilized to enhance the effectiveness of the cleaning chemical used during the midseason cleaning through removal of dissolvable constituents and micro fine particulates. Upon completion of mid-season cleaning activities, several maintenance items were undertaken including removal and repair of a stainless-steel pipe manifold and the fabrication and installation of the replacement 1<sup>st</sup> pass reject valve. The system was restarted on August 5<sup>th</sup>.

#### **7<sup>th</sup> Shutdown – RO Surge Tank Pump Failure**

Tetra Tech arrived on-site August 7<sup>th</sup> following notification from the RO system that the unit was down due to a “Remote Run Disable” alarm. Tetra Tech personnel began troubleshooting the system to identify the source of the alarm which is generic to any unexpected condition controlled by the desktop SCADA. Final diagnostic of the alarm determined that the RO Freshwater Storage tank (permeate tank) had been filled to the failsafe limit set in the SCADA due to a failure of the pump impeller on the tank discharge pump. The failed pump and motor were

removed from service and a spare unit was retrofitted to temporarily work in its place. Additionally, during the shutdown Tetra Tech personnel initiated a manual flush of the 1<sup>st</sup> pass membranes to ensure the thorough removal of raw and concentrate waters. During the flush cycle, a 2-inch fitting failed on the flush pump and began spraying water throughout the front portion of the RO building. The flush cycle was immediately terminated, and the failed piping was repaired. The manual flush cycle was reinitiated and completed without incident.

### **8<sup>th</sup> Shutdown – Lightning Strike**

On August 11<sup>th</sup>, following severe thunderstorm activity in the area, Tetra Tech personnel checked the operational status of the RO system by remote login to the SCADA system. The system appeared nonoperational and several anomalies were observed on the SCADA computer, however, the system had not initiated the remote notification protocol of automated phone calls. Tetra Tech personnel immediately mobilized to the site and upon inspection, found that the SCADA had identified a low inlet pressure alarm and multiple communication loss faults from various components of the system.

System troubleshooting over the next several days identified burnt circuitry in the Freshwater Storage tank pressure transducer, damaged fuses in both the main PLC cabinet and well head PLC cabinet, fault at the well pump variable frequency drive (VFD) control, fault on the well head flow meter, nonresponsive well head PLC communications module, and burnt circuitry on one of the main PLC input modules at the RO plant. Replacement components were procured, installed, and the system was restarted on August 16<sup>th</sup>.

Tetra Tech personnel continued trouble shooting the system faults and replaced or repaired the observed damaged components as they were identified. The repair work following the lightning damage was extremely challenging due to the complexity of how the component failures manifested. The exact circumstances of the communication stoppages were rarely repeatable and generally were random. Following a repair, the system would often operate for a period of time (varying from hours to days) without incident but then would unexpectedly fault again. With each repair, it appeared the issues had been resolved, only to have a fault or communications failure cause the RO unit to shut down again. The work that Industrial Systems was conducting over the internet required Tetra Tech personnel to physically be onsite to monitor the system and perform physical tasks and testing needed to troubleshoot the system and complete the repair work.

### **Multiple Shutdowns – PLC/SCADA Communication Failure**

During the period of August 19<sup>th</sup> through October 10<sup>th</sup> the system experienced numerous unscheduled shutdowns. Table 2, above, provides a synopsis for the frequency and approximate duration of system shutdowns and failures which continued to plague the Beal RO PLC and SCADA network following the August 11<sup>th</sup> event.

Shutdown durations ranged from a few hours up to 8 days. With the exception of a short duration shutdown on September 23<sup>rd</sup> due to a power quality issue, all shutdowns during this period were associated with ongoing electronic system communication issues as a result of the lightning strike on August 11<sup>th</sup>. During this period, Tetra Tech replaced the following components: multiple PLC and input modules in the main PLC cabinet, main PLC rack and power supply, Human Machine Interface (HMI) screen, network router, all network switches, most ethernet cables, added necessary hardware to isolate internal system communications from the internet by routing through a designated fiber optic line. Repair of the system was further complicated by the fact that finding replacement components was found to be especially challenging due to the “age” of the Beal RO unit. At 12-years in operation, the hardware platform of the PLC’s, Human Machine Interface (HMI), and communications systems are no longer manufactured or supported. The replacement components were procured through Industrial Systems and were generally remanufactured or factory certified used stock and were located through various vendors and suppliers. A more detailed progressive analysis is presented in the “Maintenance Tasks Completed During 2019” section of this report.

### Other Minor System Stoppages

Other minor system stoppages occurred during the 2019 treatment season. For example, brief shutdown and restarts needed during PLC programming changes, cartridge filter replacement, or minor maintenance activities. These stoppages did not significantly affect the system operational availability.

It is estimated that the RO system was operationally available 72% of the time during 2019. This rate was calculated based on 137 days of potential full-scale operation (May 31 to October 14) compared with approximately 98 days of actual operation due to the downtimes noted above. Overall, the RO system downtime was minimized due to significant effort by Tetra Tech and its subcontractor (Industrial Systems Inc.).

Historic RO system operational availability has been as follows:

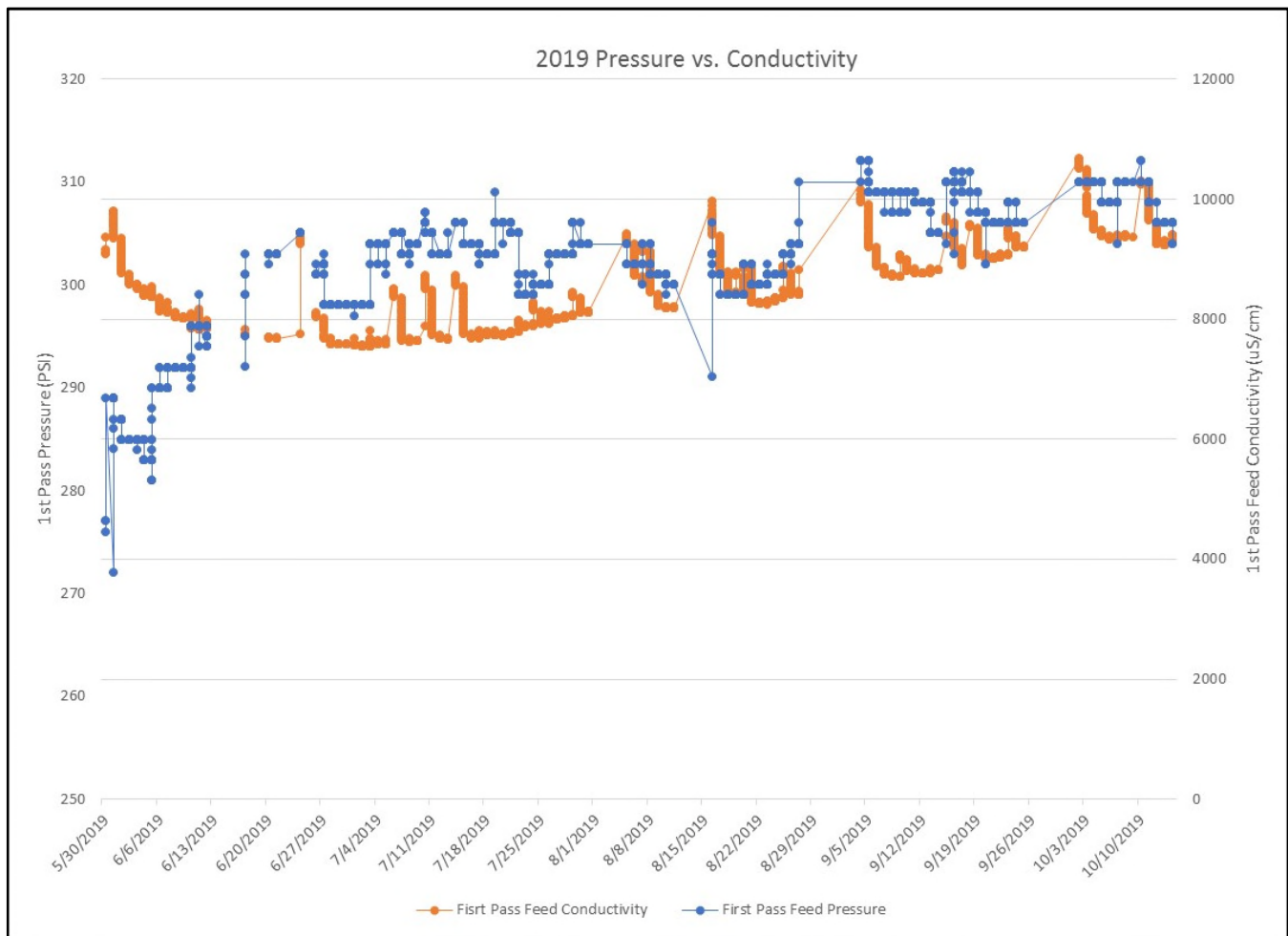
2009 - online 76% of the time  
2010 - online 96% of the time  
2011 - online 97% of the time  
2012 - online 97% of the time  
2013 - online 94% of the time  
2014 - online 91% of the time  
2015 - online 92% of the time  
2016 - online 95% of the time  
2017 – online 95% of the time  
2018 – online 92% of the time  
2019 – online 72% of the time

### BEAL RO SYSTEM WATER QUALITY

#### **General Water Quality**

2019 Beal RO Plant influent water quality was consistent with that observed during previous water treatment seasons. As has been observed in the past, influent water contained elevated Specific Conductance (SC) levels (around 10,000  $\mu\text{S}/\text{cm}$ ) during initial seasonal operation followed by a slow decrease to approximately 7,500  $\mu\text{S}/\text{cm}$  within the first two weeks of operations. During each of the many shutdown periods of 2019, the conductivity would rebound then rapidly decrease upon restart. The longer the shutdown period, the greater the rise in conductivity. This pattern continued throughout the season. A gradual increase in SC was also observed, with an ending value of approximately 9,200  $\mu\text{S}/\text{cm}$  when the plant was shut down on October 14<sup>th</sup>, 2019.

**Figure 1** below illustrates the relationship between 1<sup>st</sup> pass pressures and 1<sup>st</sup> pass (raw water) conductivity where pressure in the 1<sup>st</sup> pass generally increases as water conductivity increases. However, unlike previous treatment seasons where 1<sup>st</sup> pass pressure fluctuations generally coincide with raw water conductivity, pressures at the start of the 2019 treatment season appear lower and increased over subsequent weeks of RO operation, even though the raw water conductivity was initially decreasing. This abnormality was the result of system operational adjustments which were instituted to maximize the 1<sup>st</sup> pass permeate production and minimize the volume of raw water entering the 2<sup>nd</sup> pass feed through the systems balancing line, although these adjustments resulted in higher than normal operating pressures for 1<sup>st</sup> pass (approximately 280 psi in 2018 vs approximately 305 psi in 2019). The elevated flows through the balancing line resulted from the installation of the new second pass membranes which required higher permeate flows (2<sup>nd</sup> pass feed) than the older 1<sup>st</sup> pass membranes could provide. Several smaller spikes in the raw water conductivity can be observed in **Figure 1** which correlate to short term system shutdowns as described in **Table 2** above. Although system adjustments can help alleviate elevated pressures in the RO system, increased raw water conductivity (in general) will cause increases in the RO operating pressures.



**Figure 1 First Pass Pressure Compared with Raw Water Conductivity**

## Laboratory Chemical Analysis

Tetra Tech collected 2 (two) raw influent water samples for analysis according to Table 6 of Tetra Tech's 2012 Reverse Osmosis Water Treatment Plant Sampling and Analysis Plan (WTSAP) (Tetra Tech 2012) during the 2019 treatment season. The first sample was collected during the first week of full-time plant operations (June 6<sup>th</sup>) and the second sample was collected at the end of seasonal RO operations (October 7<sup>th</sup>). Both samples were submitted to Energy Laboratories, Inc. of Helena, Montana, for analysis. Four additional raw influent water samples were collected every other week and submitted for laboratory analysis according to an abbreviated Table 6 of Tetra Tech's 2012 WTSAP. **Table 3** shows the results of the raw influent water samples collected during the 2019 treatment season. Laboratory results are presented in **Appendix A**.

**Table 3. Raw Influent Water Samples**

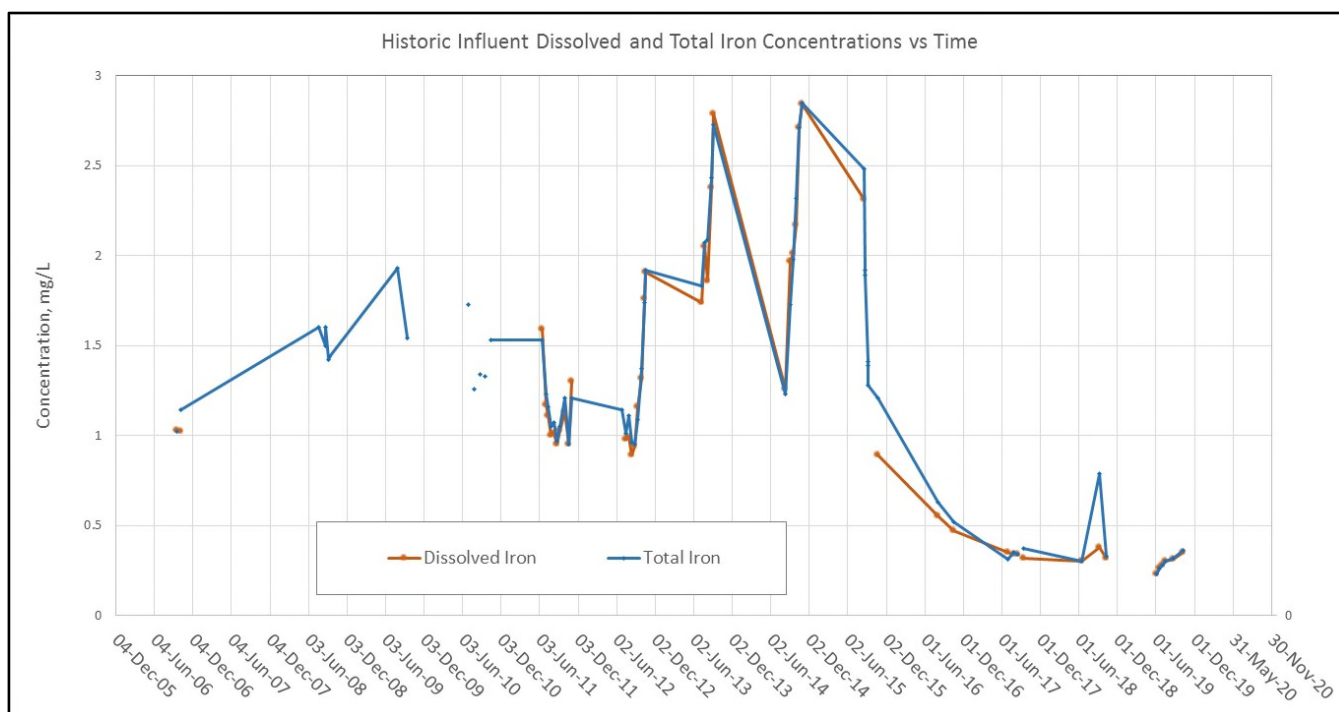
Raw Influent Water Samples	6/6/2019 Start-up	6/20/2019	7/1/2019	7/17/19	8/21/2019	10/7/2019 Shut-down
<b>Physical Properties</b>						
pH (S.U.)	7.7*					7.9*
Total Dissolved Solids (mg/L)	6950	6510	6660	6220	5930	8110
<b>Inorganics (mg/L)</b>						
Thiocyanate as N	4.1					0.69
Alkalinity, Total as CaCO <sub>3</sub>	220	200	210	220	220	210
Chloride	450	447	382	422	472	534
Sulfate	3780	4070	3720	3790	4270	4150
Cyanide, Total	0.5				0.78	0.6
Cyanide, Weak Acid Dissociable	0.004				0.094	0.004
Thiocyanate	1					2.8
Fluoride	0.4	0.4	0.4	0.4	0.3	0.4
<b>Nutrients (mg/L)</b>						
Nitrogen, Ammonia as N	15.3	14.2	14.6	15	17.4	19
Nitrogen Nitrate as N	<0.01	<0.01	<0.01	<0.01	<0.01	
Nitrogen, Nitrate+Nitrite as N	<0.01	<0.01	<0.01	<0.01	<0.01	<0.05
Nitrogen, Nitrite as N	<0.01	<0.01*	<0.01	<0.01	<0.01	0.02
Phosphorus, Total as P	0.08					0.1
<b>Metals, Dissolved (mg/L)</b>						
Calcium	513	510	512	478	497	527
Iron	0.23	0.26	0.28	0.3	0.31	0.35
Magnesium	65	64.2	58.6	56.6	62	74.6
Potassium	20	22	21	21	24	24
Sodium	1510	1510	1460	1510	1660	1820
<b>Metals, Total (mg/L)</b>						
Arsenic	0.197				0.241	0.258
Barium	0.027	0.027	0.026	0.027	0.030	0.035
Cadmium	0.00088				0.0006	0.00090
Copper	0.16				<0.01	<0.01
Iron	0.23	0.26	0.28	0.3	0.32	0.36
Manganese	0.542	0.59	0.59	0.56	0.58	0.62
Selenium	0.023				0.024	0.026
Silicon as SiO <sub>2</sub>	17	18	17.6	17.8	17.7	16.9
Silver	0.0005					<0.0005
Strontium	4.43	4.7	5	4.7	4.9	5.51

\* Analysis performed past recommended hold time

Constituents from the raw water samples were evaluated for concentration changes between the initial sample taken at the beginning of the treatment season and the end of year sample taken prior to system shutdown. Total cyanide increased slightly from 0.5 mg/L to 0.6 mg/L through the season; however, these values were lower than the minimum value observed the 2018 season despite leach pad solution levels being approximately the same. Weak Acid Dissociable (WAD) cyanide also exhibited lower concentrations during the 2019 season ranging from 0.004 mg/L to 0.094 mg/L. Thiocyanate concentrations however, increased over the treatment season from 1 mg/L to 2.8 mg/L, which is similar to values from previous seasons. Alkalinity levels remained stable at approximately 210 mg/L. Chloride level increased from 450 mg/L to 534 mg/L. Total Dissolved Solids (TDS) levels decreased throughout the first half of the season from 6,950 mg/L to 5,930 mg/L then rose sharply to 8,110 mg/L near the end of the season.

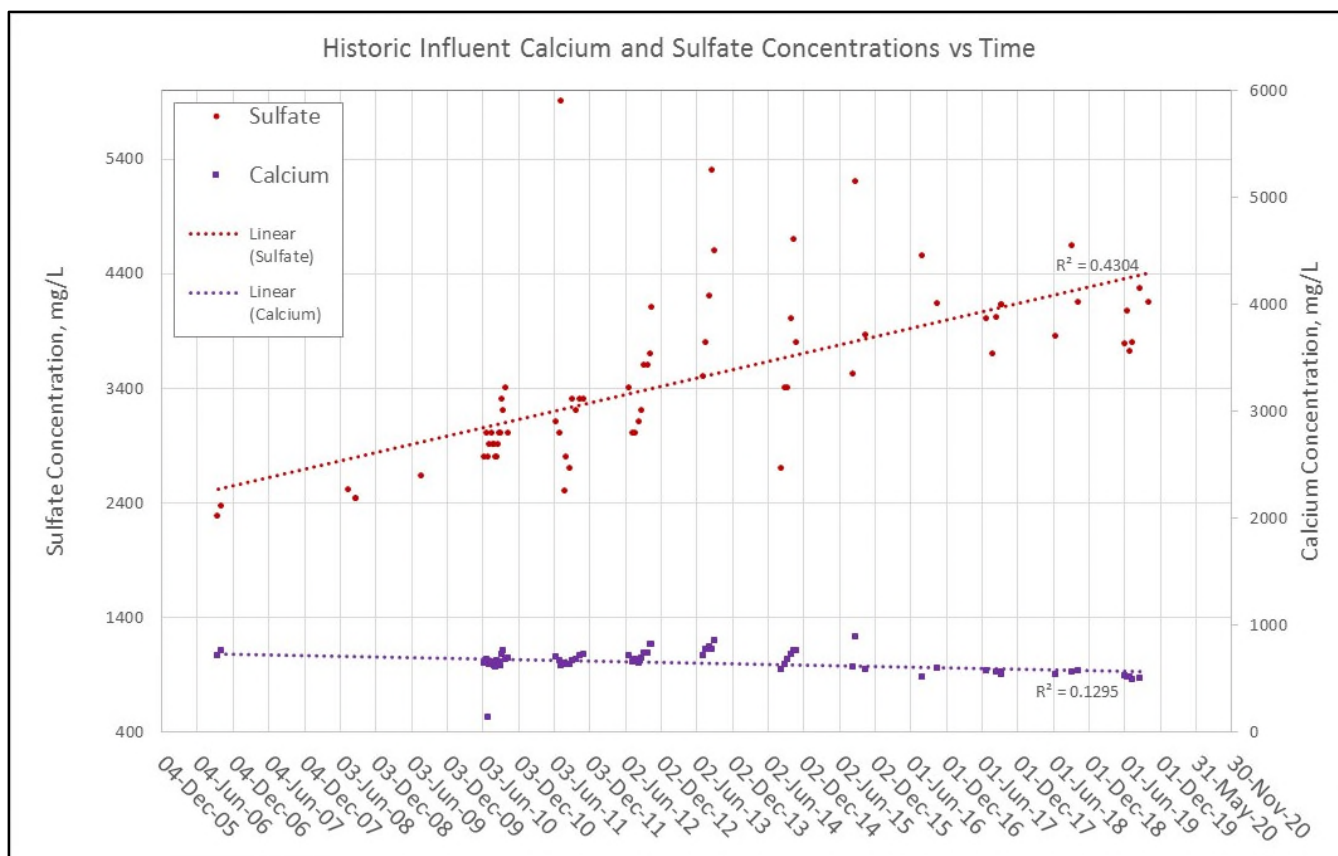
Nutrients remained relatively consistent throughout the treatment season with nitrates and nitrites below the method detection limit of 0.01 mg/L and ammonia ranging from 14.2 mg/L to 19 mg/L.

Dissolved calcium, iron, and magnesium varied slightly throughout the season but generally increased slightly by the end of the treatment season with values ranging from 513 mg/L to 527 mg/L, 0.23 mg/L to 0.35 mg/L and 65 to 64.6 mg/L, respectively. Dissolved sodium increased slightly from 1,510 mg/L to 1,820 mg/L. There were no significant changes in total metals concentrations analyzed over the 2019 treatment season.



**Figure 2. Dissolved and Total Iron Concentrations from 2011 to 2019**

Historic total and dissolved iron concentrations are shown in **Figure 2** above. The data indicates total and dissolved iron concentration values are nearly identical at varying magnitudes of concentration, indicating that most of the iron present in the leach pad is in dissolved form.



**Figure 3. Calcium and Sulfate Concentrations from 2006 to 2019**

Sulfate and Calcium concentrations were also generally consistent with the previous observations. Sulfate varied between 3,720 mg/L and 4,270 mg/L while calcium concentrations varied between 478 mg/L to 527 mg/L. 2018 concentration values for sulfate and calcium in raw water varied between 3,850 mg/L and 4,150 mg/L and 525 mg/L to 569, respectively.

**Figure 3** above illustrates an upward trend in sulfate concentrations of Beal RO raw water since 2006 while calcium concentrations, although with significantly less available data, appears to be trending slightly downward.

Compliance testing for the RO discharge to German Gulch was conducted under the Beal Site Wide Monitoring task. Sampling completed during June was conducted after RO system startup activities but prior to discharge activities and is representative of site conditions without treatment system discharge. During this period, ammonia was below the method detection limit while total cyanide and total recoverable selenium were slightly above their respective chronic aquatic life standards (MDEQ 2019). Selenium and cyanide documented for this period is not associated with treatment system discharge. Additional compliance testing was completed on September 16 during active treatment system discharge as part of Site Wide Monitoring. During this event, all constituents of concern were below chronic-aquatic life standards, and most were below method detection limits.

Laboratory analytic results of all samples collected as part of RO operations during the 2019 treatment season are attached in **Appendix A** and include performance samples associated with cleaning operations.

Results of raw water sampling suggest that leach pad water chemistry did not change significantly over the course of the treatment season.

## Field Tests

Water chemistry tests were performed throughout the 2019 treatment season utilizing field meters and field test kits (Hach®). Samples for field analyses were collected from four locations along the treatment flow path; INF-01 (raw influent water), INF-02 (Post Multi Media Filter (MMF)), 1<sup>st</sup> Stage Permeate (second stage feed), and 2<sup>nd</sup> Stage Permeate (final treated water). The results were recorded and used to analyze the system performance and implement any necessary adjustments to the treatment process. The four monitoring locations are arranged as follows:

- INF -01 (raw influent water) – This monitoring location is used to observe raw influent water pumped from the leach pad prior to being filtered through the MMF's;
- INF-02 (Post MMF) – Monitoring location after MMF's, but before 1<sup>st</sup> stage membrane arrays. Utilized to measure the effectiveness of the MMF's;
- 1<sup>st</sup> Stage Permeate – This monitoring point is on the low-pressure side of the 1<sup>st</sup> stage membrane arrays and before the water enters the 2<sup>nd</sup> stage membrane arrays of the RO system; and
- 2<sup>nd</sup> Stage Permeate – This monitoring point is on the low-pressure side of the final 2<sup>nd</sup> stage membrane array and represents treated water exiting the RO treatment system.

Influent (Raw Water) field conductivity ranged from a minimum of 7,500  $\mu\text{S}/\text{cm}$  on July 1<sup>st</sup>, after the system had been running for approximately 1 month, to its highest value of 9,330  $\mu\text{S}/\text{cm}$  on October 7<sup>th</sup>, resulting in an overall change of approximately 1,830  $\mu\text{S}/\text{cm}$  as compared to a 3,730  $\mu\text{S}/\text{cm}$  change observed during 2018 and 3,143  $\mu\text{S}/\text{cm}$  change observed during 2017.

2018 field-tested chlorine concentrations remained at or just above the method detection limit. Results of laboratory analysis for chlorine degradation by-products were below the method detection limits. Review of both the field and laboratory results suggests the field test kits may be biased high and that in fact chlorine is not present in the raw influent water at measurable concentrations.

## Membrane Cleaning

Prior to the start of the RO unit, several of the first pass membrane elements (first element of each vessel; 4 vessels per array; A, B, and C arrays in 1<sup>st</sup> pass) required cleaning due to observed debris lodged in the feed ends of the elements. The debris included small particulates of precipitated scale, sand-like particles, and other organic debris which had been observed during removal of the elements in the prior year. Membranes of the "B" and "C" arrays were installed just as they had been in 2018. The four (4) elements located at the feed side of the "A" array were reversed and placed in the back end of the vessels so that any debris dislodged would be removed with the waste stream during normal operations. The A and B arrays were then mechanically isolated by replacing the feed manifold which normally distributes feed waters to both arrays simultaneously (see Photo 1 below) with a single feed manifold (see Photo 2 below) and each array was then flushed with the CIP unit so that any debris dislodged would be captured by the CIP filter system.

### Feed Manifold A and B Arrays



Photo 1. RO A & B Arrays manifold feeding both arrays simultaneously.

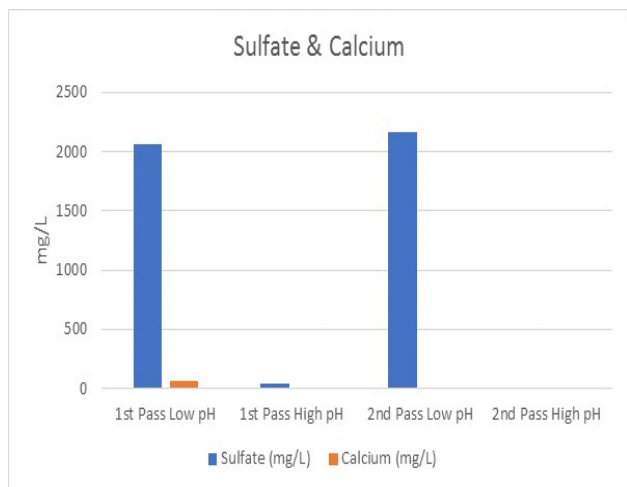


Photo 2. Single manifold placed to feed A or B array independently during cleaning operations.

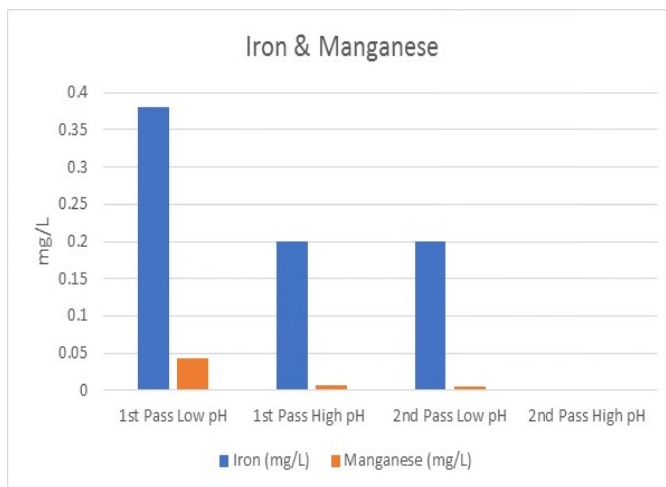
Tetra Tech conducted a mid-season cleaning of the RO membrane elements between July 31<sup>st</sup> and August 5<sup>th</sup>. Cleaning activities were initiated by pumping 2<sup>nd</sup> pass permeate water into each array of the 1<sup>st</sup> and 2<sup>nd</sup> passes of the RO system and allowing the system to soak overnight to loosen particulates and help dissolve precipitates. The CIP skid was then utilized to conduct a two-step chemical cleaning process of low pH solution followed by high pH solution. The first step utilized a cleaning solution of OptiClean™H and RO permeate water. OptiClean™H is a proprietary aggressive low pH, low foaming cleaner formulated to remove metal hydroxides, calcium carbonate, calcium phosphate and other inorganic scale. This product was chosen specifically to combat inorganic fouling that has traditionally been observed on the RO membrane elements and its ability to help reduce gypsum. Cleaning operations included mechanically isolating each array, pumping clean permeate water through each array at a targeted rate of 35-40 gallon per minute per membrane element with a maximum pressure of less than 60 psi. OptiClean™H was then mixed with permeate water in the CIP mixing tank to the concentrations recommended by the manufacture and the solution was recirculated through each array at the targeted rates stated above. Each array was then flushed with clean permeate water until the exiting solution was within 1 pH unit of the raw permeate water. The second cleaning step followed the same process but used a cleaning solution of OptiClean™B. OptiClean™B is a proprietary aggressive high pH, low foaming cleaner formulated to remove organic fouling. After the mid-season cleaning was completed, the system was allowed to soak in clean permeate for 48 hours prior to restarting.

An end of season cleaning of the membranes was performed between October 15<sup>th</sup> and October 18<sup>th</sup>. The cleaning entailed an initial system flush and soak with 2<sup>nd</sup> pass permeate water followed by use of the CIP Cleaning Skid with a low pH cleaner (OptiClean™H) as described above, followed by a thorough rinse with clean permeate water, then a high pH cleaner (OptiClean™B) as described above, followed by a thorough rinse with clean permeate water, and finally, a preserving solution consisting of 1% sodium metabisulfite (by weight) was pumped through the RO elements.

During both the mid-season and end of season cleaning events, samples were collected of the cleaning solution after flushing through the 1<sup>st</sup> pass and 2<sup>nd</sup> pass membranes. **Figure 4** and **Figure 5** below show the concentration of calcium, sulfates, iron and manganese after the cleaning solution was flushed through the membranes. The low pH cleaner seems to be effective at removing calcium and sulfate deposits as well as iron and manganese from the membranes. The high pH cleaner appears to be effective at removing additional iron from the membranes. Laboratory results are presented in Appendix A.



**Figure 4. Calcium and Sulfate Concentration in Cleaning Solution**



**Figure 5. Iron and Manganese Concentrations in Cleaning Solution**

## RO Membrane Maintenance

Tetra Tech conducted two scheduled soak periods as a preventative maintenance measure and three (3) unscheduled opportunistic soak periods during the 2019 operations. The first scheduled soak was completed June 22 through June 24 and the second scheduled soak was July 31 to August 1 just prior to the mid-season cleaning. Three extended soak periods were completed during unscheduled system down time presented in **Table 2** above. These periods included August 11 through August 15, August 27 through September 4, and September 25 through October 2, 2019. Because flow and pressure adjustments to the RO system are required following the soaking periods, improvements to RO membrane performance is difficult to identify when comparing before and after data. However, observations of system fluid conductivity following soaking periods have identified significant increases in SC values. Example: Clean 2<sup>nd</sup> pass RO permeate water (SC≈20 µS/cm) is pumped into the 1<sup>st</sup> pass vessels at low pressure. This process is identified as a “flush cycle” because the water is pushed through the membranes at low pressure not intended to generate permeate, therefore, the water flows through the membranes “flushing” the salts and contaminants from the membrane surface and pore spaces. This “flushing” process continues until the first stage discharge (reject flow) SC concentration is approximately equal to 300 µS/cm or less. The system is then allowed to soak for a minimum of 18 hours, and, upon re-initiation of a flush cycle, the 1<sup>st</sup> pass discharge waters now have SC values approximately equal to 1,500 µS/cm or more, 75-times greater than the water originally pumped into the 1<sup>st</sup> pass vessels.

The Beal RO system was not designed to allow a soaking period for the 2<sup>nd</sup> pass membranes as the quality of the water entering the 2<sup>nd</sup> pass was intended to be clean enough (<300 µS/cm) that soaking periods would not be necessary. However, the Beal RO system was designed with a “bypass valve” (valve YV125A) which was intended to allow minor amounts of raw water into the second pass feed stream if needed (such as system

startup) but generally allow excess 1<sup>st</sup> pass permeate to flow back into the 1<sup>st</sup> pass feed stream. In reality, valve YV125A allows raw untreated water (up to 60+ gpm) to flow into the 2<sup>nd</sup> pass feed stream which greatly increases 2<sup>nd</sup> pass feed constituent concentrations and pressures. The divergence from design is believed to be due to increases in raw water constituent chemistry, degradation of the media in the MMF's, and degradation of the 1<sup>st</sup> pass membrane elements. To combat the possible negative effects of this situation, Tetra Tech personnel pumped permeate water into each array of 2<sup>nd</sup> pass utilizing manual valve overrides during each soak event or periods of extended downtime.

At the end of the 2019 treatment season, the RO membrane elements were cleaned utilizing the CIP system (as discussed above), preserved with a 1% sodium metabisulfite (by weight) solution, and removed from the Beal RO system. Upon removal from the RO unit, each membrane was drained of excess solution, and a year-end inspection consisting of physical examination for signs of scaling or other damage of each membrane was performed. Each membrane was then placed in a new storage bag with both ends heat-sealed closed to protect the membrane element from drying out during storage. The 1% sodium metabisulfite solution is utilized to inhibit microbial growth during long term storage.

## RO Membrane Performance Normalization

Membrane performance in RO operations can be evaluated through a variety of data tracking and calculated parameters. Standard calculated parameters for RO systems in the industry often include differential pressures, net driving pressures, normalized permeate flows, salt passage or rejection, differential pressure drop coefficient, and permeability. Tetra Tech collected a variety of data throughout the 2019 operational season in order to calculate several of the parameters listed above. However, utilizing these parameters for membrane performance for the Beal RO system is difficult to evaluate in detail due to the following:

- Frequent system downtime – Beal RO system downtime, even for short periods of time, results in increased feed solution constituent concentrations (increased SC values) followed by a general downward trend in concentrations as exhibited in the 1<sup>st</sup> Pass Conductivity shown in Figure 1 above. Although these increases in SC are consistent in occurrence, they are not consistent in magnitude, duration, or the subsequent decrease. These observations are consistent with observations from previous years operations and is suspected to be the result of stratification of solution in the Beal leach pad and can result in data volatility.
- Operational adjustments – Operational adjustments to the Beal RO system are routinely performed to maintain appropriate flows and pressures and are often dictated by variations in the feed solution constituent concentrations. Adjustments of the Beal RO system can include feed water flow and pressure for 1<sup>st</sup> and 2<sup>nd</sup> passes, reject solution flow and pressure for 1<sup>st</sup> and 2<sup>nd</sup> passes, and leach pad well solution flow and pressure. Change to flow or pressure at any one of these locations can result in data volatility.
- Equipment calibration – Flow meters, SC meters, and pH meters require frequent checks and calibrations. Most calibration adjustments tend to be minor (less than 1% of display value) but those adjustments can skew data results.
- Variable feed solution constituent concentrations – Feed solution concentration to the RO system varies throughout the season. Decreases, as observed during early season operation, or increases in constituent concentrations due to down time or late season operations, trigger manual system adjustments to maintain appropriate flow and pressures in the system.
- Deteriorated condition of the 1<sup>st</sup> pass concentrate valve and 2<sup>nd</sup> pass feed valve.

Tetra Tech personnel collected specific data during the 2019 operational season to evaluate and optimize RO operations at the Beal Mountain site. The data collected included conductivity and pressure data for both feed and reject stream flows for each individual array of the RO system (1<sup>st</sup> Pass – 1<sup>st</sup> Array, 1<sup>st</sup> Pass – 2<sup>nd</sup> Array, 2<sup>nd</sup> Pass- 1<sup>st</sup> Array, 2<sup>nd</sup> Pass- 2<sup>nd</sup> Array, and 2<sup>nd</sup> Pass- 3<sup>rd</sup> Array). The data collected must then be “normalized” which is a technique used to evaluate if changes in flow or rejection are most likely caused by membrane fouling, membranes degradation, or just due to changes in operating conditions (Lenntech, 2001). The data can help to

determine cleaning regiments, chemical feed rates, and general system adjustments to help reduce the likelihood of creating conditions in the RO system which could lead to mass fouling of the elements.

Overall, the following system performance metrics suggest possible fouling of the 1<sup>st</sup> pass membranes during the early part of the season followed by improved performance latter in the season.

### Net Driving Pressure

The data collected was utilized to calculate Net Driving Pressure (NDP) which is essentially the sum of all forces acting on the membrane. These may include pump or feed pressure; back pressure from line restrictions and storage tank; and osmotic pressure of the feed and permeate waters. The net driving pressure is the measure of the actual driving pressure available to force the water through the membrane. As net driving pressure increases, the flux (permeate production) increases proportionally (given all other factors are held constant).

The average NDP<sub>a</sub> was calculated utilizing the following equation:

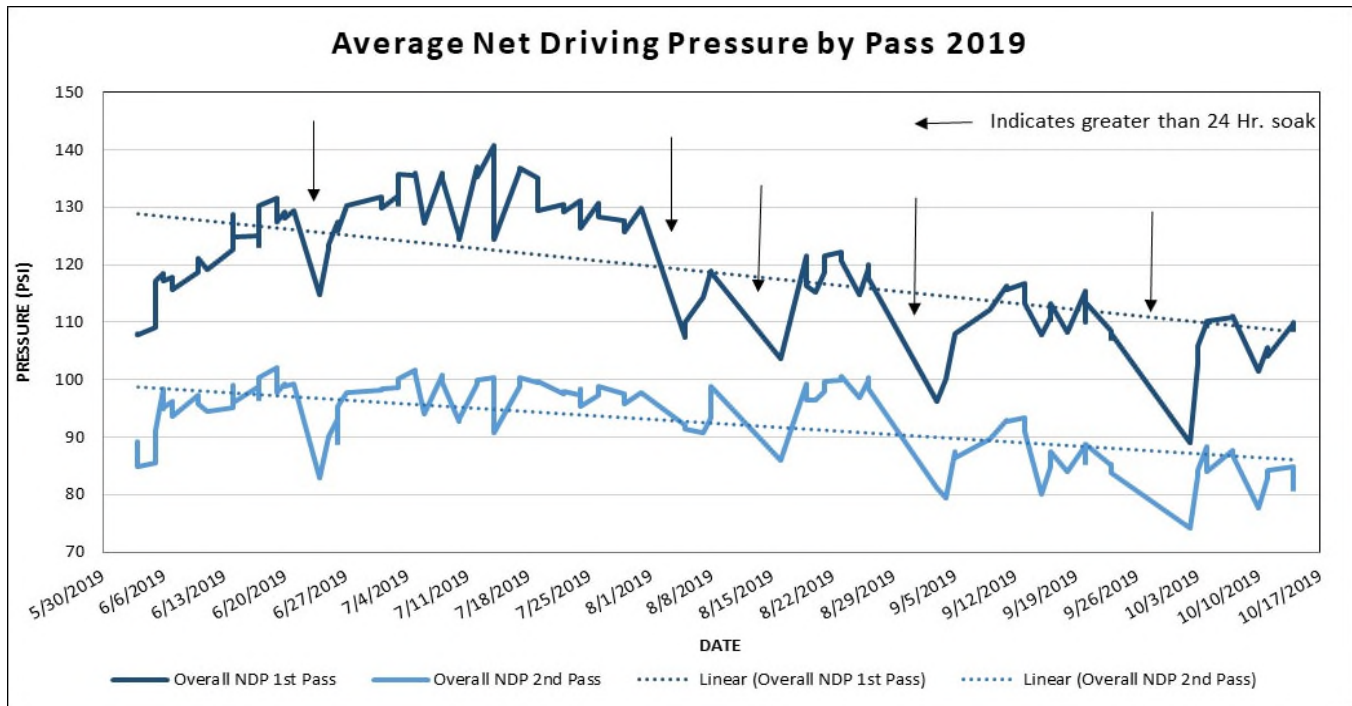
$$NDP_a = P_f - P_p - P_o$$

Where	NDP <sub>a</sub> = Average Net Driving Pressure
	P <sub>f</sub> = Average Feed Pressure (average of feed and concentrate pressures)
	P <sub>p</sub> = Pressure in the permeate line (gauge pressure)
	P <sub>o</sub> = Average Osmotic Back Pressure of feed water (average of feed and concentrate salt concentration divided by 100)

Generally, P<sub>o</sub> is calculated utilizing Total Dissolved Solids (TDS) values; however, for the Beal RO Plant this data is calculated utilizing the plant Specific Conductance (SC). This is done for convenience as plant in-process meters measure SC and because analysis of historic field data collected indicates that the relationship between SC and TDS is generally consistent.

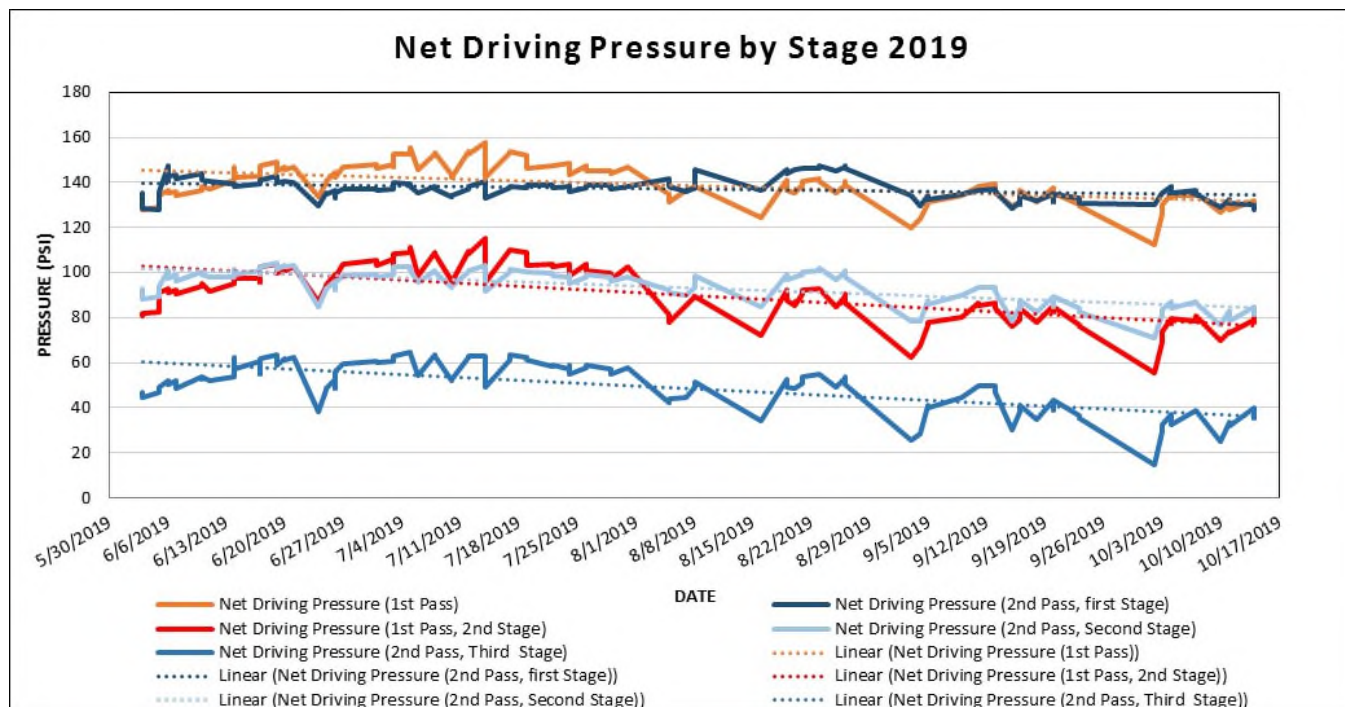
The NDP will begin to increase over time due to fouling or scaling of the RO membranes and it is common practice in the industry to instigate a membrane cleaning regiment when NDP increases by 15% to 25% above baseline value. Volatility and significant decreases in NDP can be due to variances in instrumentation (calibration of meters), errors made during data collection, significant system adjustments on nonautomated RO operations (such is the case a Beal), or influence from effective cleaning or soaking events.

When NDP is monitored for each stage of a RO system, problems can be identified between fouling and scaling based on the location of increases in pressure. An increase in NDP in the front stage of a RO indicates possible fouling issues while increases in NDP in a second stage indicates scaling. In general, average NDP increased over the first month of operation during the 2019 season then generally decreased during the second half of the operational season, ending at approximately the same value as at startup (**Figure 6**). **Figure 7**(below) displays NDP data for each array of the Beal RO system.



**Figure 6. Average Net Driving Pressure**

A slight overall increase in NDP would be expected in normal RO operations, particularly where systems are being operated near the upper limits of capacity for feed water chemistry, such as the case with the Beal RO system. The decreases in NDP throughout the second half of the season correlate with the mid-season cleaning (completed 08/05/2019) and the frequent system downtime which were used as soak events. It would appear that any fouling or scaling that may have occurred during the early season was removed by the midseason cleaning and that the frequent soak events resulted in minimal or no net accumulation of membrane fouling during the 2019 season. Additionally, the data tends to suggest that extended soaking periods can be nearly as effective as the cleaning events.



**Figure 7. Average Net Driving Pressure by Pass and Stage**

As stated above, evaluation of this type of data is complicated due to the everchanging feed water chemistry which results in continual system adjustments in order to maintain the appropriate flows and pressures. For most RO systems, feed water chemistry is generally consistent, so frequent system adjustments are not required which results in a much smoother graph.

Tetra Tech plans to continue the collection of RO data for the NDP calculation during future operations in order to develop better baseline data and the development of RO membrane cleaning protocols. Plant field data and the resulting calculated values for NDP are presented in **Appendix B – Tables 1 and 2**.

### Normalized Permeate Flow

The data was also utilized to calculate Normalized Permeate Flow (NPF) which is a comparison of RO permeate flow in the present operational conditions to the baseline permeate flow. The purpose of flow normalization is to account for variable input parameters such as net driving force and temperature, both of which have tremendous effect on permeate flows. The effect of these parameters is “normalized” to properly analyze the membrane performance.

Once NDP has been determined, NPF may be calculated based on NDP and temperature using the following equation:

$$NPF = \frac{(TCF \text{ today } ^\circ F) \times (NDP \text{ startup (PSI)}) \times (Permeate \text{ Flow (GPM)})}{(NDP \text{ today (PSI)}) \times (TCF \text{ startup } ^\circ F)}$$

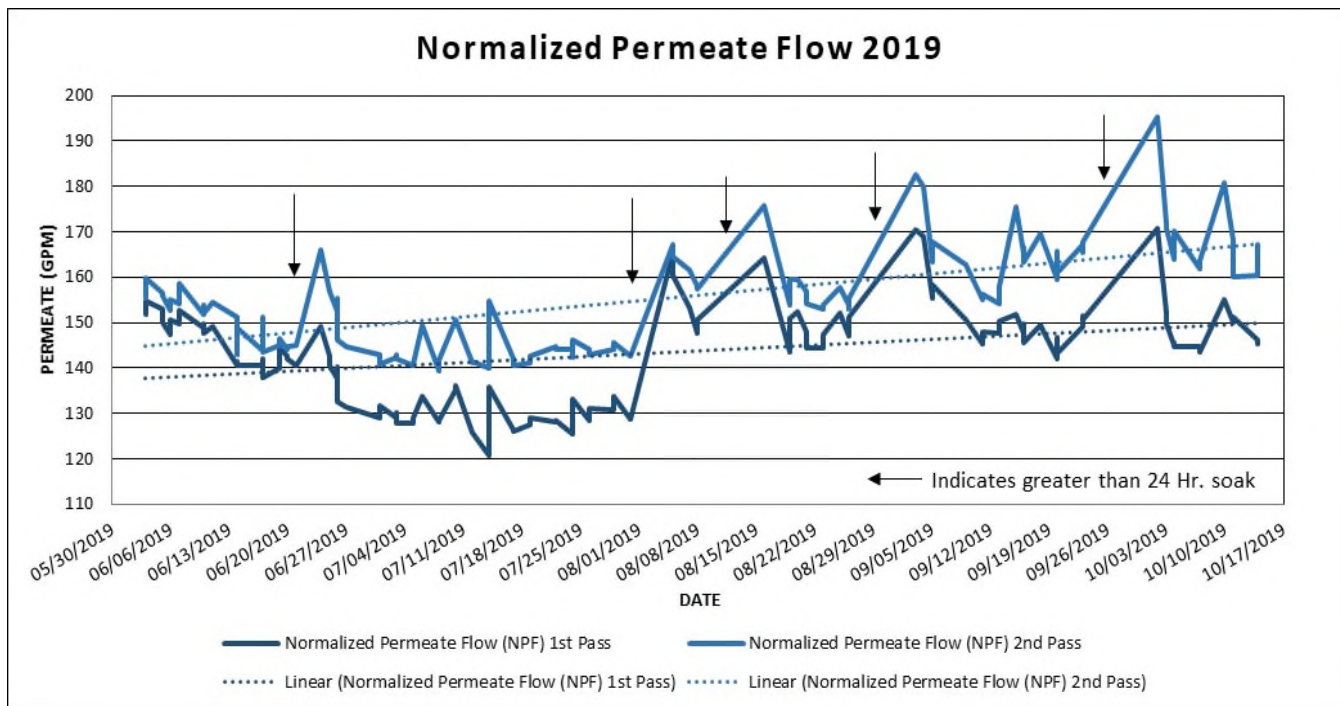
Where

NDP = Net Driving Pressure

NPF = Net Permeate Flow

TCF = Temperature Correction Factor (published values)

NPF measures the amount of permeate water that the RO is producing. A decrease in NPF could indicate that the membranes require cleaning while increases in NPF suggest either improved feed water quality (lower TDS), decreases in membrane foulant, possible leakage of brine seals or other membrane damage. NPF should always be evaluated with other operating parameters and take into account any system adjustments that also contribute to any NPF values. For instance, NPF increases combined with increased permeate conductivity may suggest brine seal leakage or membrane damage. In general, NPF in 1st and 2nd passes declined during the first month of operations, stabilizes during the second month, then increases through the remainder of the season (**Figure 8**). This suggests that during early season operations, fouling may have occurred. The removal of foulant during the mid-season cleaning combined with frequent soak periods associated with system down time resulted in improved system performance but still a slight net decrease in 1st pass membrane performance.



**Figure 8 Beal RO Normalized Permeate Flow**

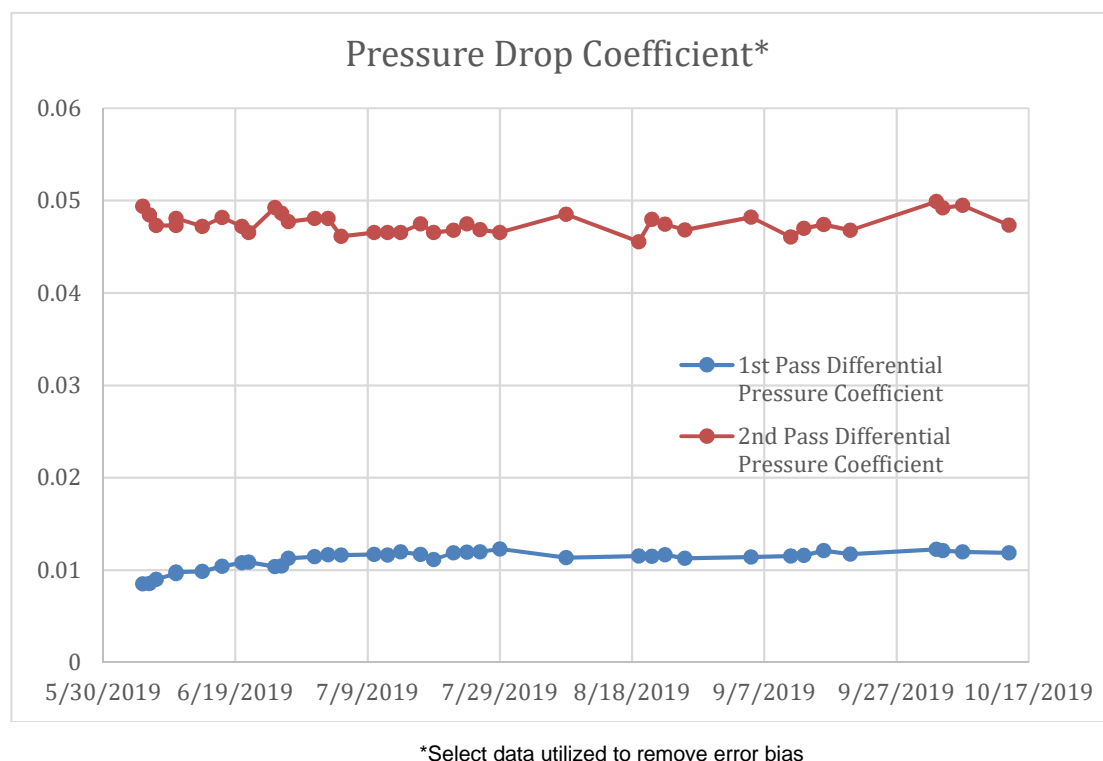
The data presented here is not definitive for several reason. The baseline for this data comparison was chosen as the season startup, which may contain significant bias. Second, the system was designed with a bypass line connecting first pass feed (raw water) and second pass feed (1<sup>st</sup> pass permeate) to help balance feed pressures to each booster pump. However, flows between the bypass line can vary significantly during operation which will alter the “normalization” of the data for second pass. Finally, system adjustments to operating pressures, flows, and permeate production will also impact the “normalization” values. When significant system adjustments were made, plant values were first recorded prior to those adjustments and then after to evaluate the effects of the adjustments on NDP and NPF. Plant field data and the resulting calculated values for NPF are presented in **Appendix B – Tables 1 and 2**.

### Differential Pressure Drop Coefficient

Differential pressure drop, is the difference between feed pressure and concentrate pressure, for a single array or pass. The Differential pressure drop coefficient attempts to normalize differential pressure for changes in flow.

$$\text{Pressure Drop Coefficient} = \frac{(\text{Pass Pressure Drop}(\text{psi}) \equiv [\text{Pass Feed Pressure} - \text{Pass Concentrate Pressure}])}{([\text{Pass Feed Flow}(\text{gpm}) + \text{Pass Concentrate Flow}(\text{gpm})]/2)^{1.5}}$$

In general, increases in the differential pressure drop coefficient are often used as an indicator of obstruction to flow (fouling) within the system. Foulant may be associated with particulates, biological growth, or dissolved solids precipitation (scale). Fluctuations in the coefficient can also be attributed to system adjustments, meter calibrations, feed and concentrate valve functionality, and system stabilization following shutdowns / restarts.



**Figure 9. Calculated Pressure Drop Coefficient**

Increases in the 1<sup>st</sup> pass differential pressure drop coefficient during the first month of operations supports possible membrane fouling followed by more stable performance; however, there were also significant system adjustments that occurred during the first few weeks of operation. The variability of 2<sup>nd</sup> pass coefficient values are likely due to operator adjustments to balance the system which resulted in fluctuations of the 2<sup>nd</sup> pass feed concentrations due to varying amounts of raw water passing through valve YV125A, instrument calibrations (flow meters and transducers), and issues associated with the deteriorating condition of the 2<sup>nd</sup> pass feed valve.

Tetra Tech plans to continue the collection of RO data for the differential pressure drop coefficient calculation during future operations in order to develop better baseline data and refine sampling protocols.

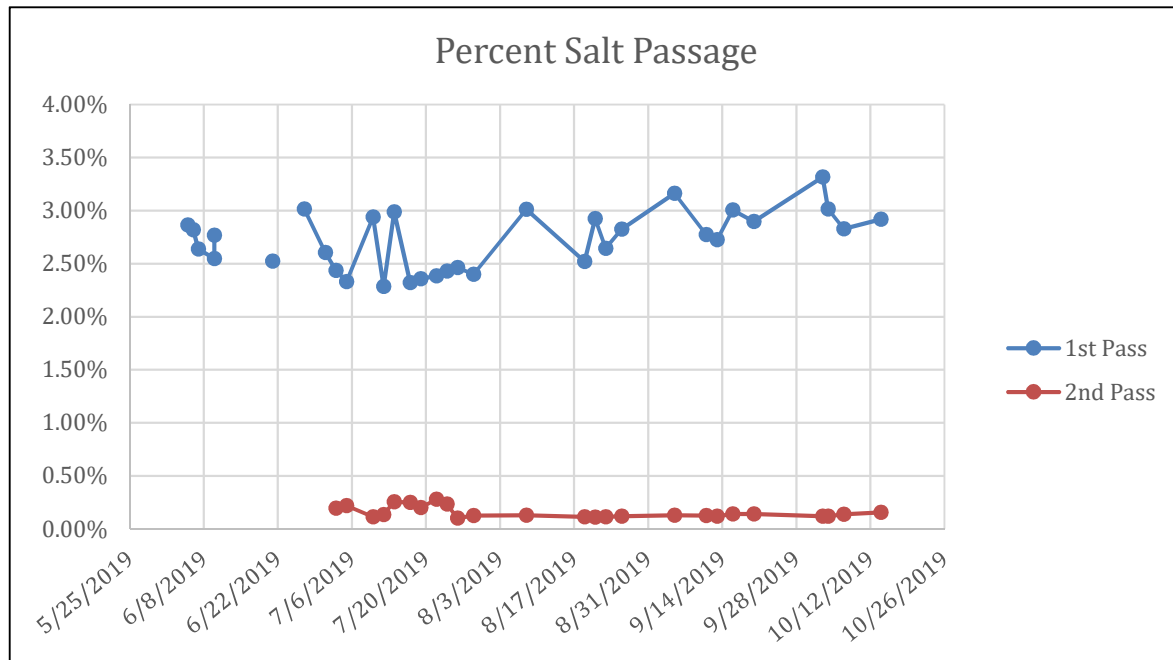
## Percent Salt Passage

Percent salt passage uses feed conductivity, concentrate conductivity, and permeate conductivity to evaluate membrane performance.

$$\% \text{ Salt Passage} = \frac{(\text{Pass Permeate Conductivity (SC)}) \times 2}{(\text{Pass Feed Conductivity (SC)} + \text{Pass Concentrate Conductivity (SC)})}$$

An increase in salt passage may be due to leaking brine seals, fouling, improper pH, high recovery rate, too high or low feed pressures, or changes in feed water chemistry. Initial evaluation of the relevant data collected during 2019 for this metric appears to suggest that 1<sup>st</sup> pass salt passage generally increases ( ) through the season and may suggest either membrane fouling/scaling or excessive operating feed pressure; however, significant system adjustments, instrument calibrations (SC meters), and operational constancy should be recognized as a significant contributor to the data variation. Second pass salt passage appeared to remain relatively stable throughout the season.

Tetra Tech plans to continue the collection of RO data for the percent salt passage calculation during future operations in order to develop better baseline data, evaluate membrane performance, and refine element cleaning protocols.



**Figure 10 Percent Salt Passage**

## Summary of RO Performance

Evaluation of the collective data for the RO during 2019 for net driving pressures, normalized permeate flows, salt passage, and differential pressure drop coefficient suggest the following:

- Mid-season cleaning was effective at removing early season fouling or scaling.
- Frequent extended soak events maybe nearly as effective as cleaning events resulting in minimal or no net fouling or scaling.
- The presence of the YV125A bypass and system adjustments to manage changes in feed chemistry must be considered when evaluating system performance metrics.

## Maintenance Tasks Completed During 2019

The RO system at Beal Mountain has completed its twelfth season of operation. Many of the system components are original equipment installs and due to their age, will have a higher probability for failure, especially when operating under the more strenuous conditions. Major maintenance projects completed in the 2019 operational season are listed below.

### Replacement of Second Pass Membranes

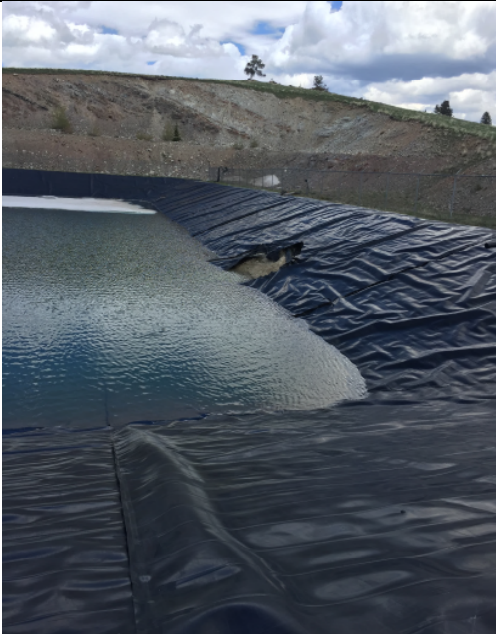

The 2018 Year 11 water treatment statement of work included a line item for the purchase and installation of 35 new second pass membranes. This work was not completed during the 2018 operable season; however, the replacement membranes were purchased under that statement of work. The replacement membranes were installed at the beginning of the 2019 operable season. During installation of the new membranes it was found that the new membranes have a smaller opening on the permeate port such that the membrane to vessel end cap adapter was not compatible. After a short delay, appropriate end cap adapters were obtained and installed without incident.

### Freshwater Pond Investigation

As part of the RO treatment process, permeate water is pumped from the RO Freshwater Storage tank to the freshwater pond located north of the RO building. The pond is utilized to provide the treated water additional exposure to air and sunlight in order to help reduce any residual ammonia (aeration of the water) or cyanide (hydrolyzed in sunlight). At the beginning of the 2018 operating season, a large tear in the Freshwater Ponds PVC liner was observed. Prior to contracting the repair of this liner further evaluation of liner integrity was deemed prudent.

The 2019 Year 12 water treatment statement of work included a line item for dewatering the Freshwater Pond with existing equipment in order to visually inspect the integrity of the synthetic liner. During the period of September and October 2019, the water level in the Freshwater Pond had been drawn down far enough to inspect and sample accessible sediments. Findings were as follows:

- Pond dimensions are approximately 250' x 250' x 50' deep with 1.75:1 slopes.
- The Liner material was compromised in multiple locations and consisted of rips, tears, and separated seams. Compromises were identified on all four pond slopes and at numerous elevations (i.e. above and below the typical water levels in the pond).
- Miscellaneous debris was observed at or near the bottom of the pond which included pipe, pipe fittings, and geotextile fabric.
- Sediment present was highly liquified with low cohesive strength.
- One shallow grab sample of sediment was obtained and submitted for laboratory analysis. Results indicate:
  - Non-detect for RCRA metals
  - Total Cyanide = 6.1 mg/kg
  - Weak acid dissociable cyanide = 0.5 mg/kg
  - Free cyanide =<4 mg/kg
  - Total Extractable Hydrocarbons = 988 mg/kg
    - <31 mg/kg C9-C18 Aliphatics
    - 321 mg/kg C19-C36 Aliphatics
    - 54 mg/kg C11-C22 Aromatics
  - 10.7% organic matter
- Total sediment depth estimated to be three feet but not confirmed. Therefore, sediment volume estimated to be 16,875 cubic feet (582 cubic yards).
- Chemistry of deeper sediments remains unknown.

Beal RO Room Sump Disposal System	
	
Photo 3. Tear in Freshwater Pond liner spring of 2018.	Photo 4. Freshwater Pond – September 2019.

### First pass reject valve replaced

Tetra Tech personnel purchased a replacement 1<sup>st</sup> pass reject valve and flanges which required custom welding and fabrication in order to fit the location. The original valve had been vibrating excessively during the past operating seasons and had become worn to the point that it is no longer functioning. The valve was fabricated and installed on August 2<sup>nd</sup> while the system is down for the mid-season membrane element cleaning.

### Second Pass feed valve replaced

Tetra Tech personnel purchased and replaced the 2<sup>nd</sup> pass feed valve on October 2<sup>nd</sup>, 2019. The valve, which was original to the system (2008), had become worn over time and began vibrating profusely shortly after startup during 2019 operations. Issues with the valve were most likely exasperated with the replacement of the 2<sup>nd</sup> pass membrane elements and system adjustments implemented to reduce the volume of raw water entering into the 2<sup>nd</sup> pass of the system.

### CIP heaters installed

Two heating elements and their related controls were installed in the CIP system on July 24<sup>th</sup>, 2019. The use of heated water for cleaning solution is recommended by the membrane manufacturers because it can be more effective and efficient at removing fouling. Installation included installing a temporary larger power supply cable to the Connex container and connecting heater controls to safety shutoff switches on the CIP.

### Freshwater Storage Tank pump impeller Replacement

On August 7<sup>th</sup>, the Beal RO unit experienced a system stoppage due to the failure of the impeller in the storage tank pump located immediately north of the Beal building. The pump and motor were removed and upon

inspection, it was discovered that the impeller had completely separated from the motor shaft adaptor. The cause of the damage was not discernable but may have been due to general fatigue as the pump and motor are original to the system (2008) or may have been caused from debris entering the pump from the storage tank as the tanks roof has degraded significantly in the past few years. Tetra Tech installed a temporary replacement pump which is undersized for this operation but continued to work throughout the season. Repair components were procured and installed during demobilization activities and the repaired pump will be installed prior to the 2020 operational season.

## **Exterior Lighting on South and West Building**

Additional LED outdoor lights were added to the exterior of the building during the 2019 operational year. One existing (partially functioning) light was replaced on the south side of the building and two (2) new units were installed on the west side to alleviate health and safety concerns associated with working at the site during dark hours.

## **RO PLC and SCADA Communication**

On August 11<sup>th</sup> at approximately 06:45, a significant electrical surge passed through the Programable Logic Controls (PLC) communications networks at both the RO Water Treatment Plant and at the extraction well located south of the plant. Tetra Tech personnel were notified of the plant shutdown via remote call system and traveled to the site to investigate. Upon arrival at the Beal Mountain site, severe thunderstorm activity was observed in the form of significant lightning, surface water runoff, and hail accumulations exceeding 6-inches. Initially, it was discovered that a pressure transducer located in the permeate water storage tank was not functioning (visible electrical scorching), PLC networks (three total) were not communicating, and the well Variable Frequency Drive (VFD) controller had faulted. Failed component replacement and system trouble shooting continued from August 11<sup>th</sup> through August 16<sup>th</sup> with help from our computer integration subcontractor Industrial System, Inc.

Industrial Systems is based in Vancouver, Washington but was able to remotely access the system to help identify faulty components and direct troubleshooting efforts. As damaged components were identified and replaced, it was discovered that additional components were either intermittently functioning or only partially functioning and needed repair or replacement. Finding replacement components was found to be especially challenging due to the “age” of the Beal RO unit. At 12-years in operation, the hardware platform of the PLC’s, Human Machine Interface (HMI), and communications systems are no longer manufactured or supported. The replacement components were procured through Industrial Systems and were generally remanufactured or factory certified used stock and were located through various vendors and suppliers. Additionally, most of the specialized hardware procured through Industrial Systems required programming that had to be completed through proprietary licensed software at their facility.

The system operated intermittently upon restart on August 16<sup>th</sup> through August 27<sup>th</sup> when the HMI unit stopped working altogether. Upon installation of a remanufactured HMI unit on September 4<sup>th</sup>, the system again ran intermittently through early October as various components were replaced and programming was altered to bypass problematic hardware. From August 12<sup>th</sup> through October 2<sup>nd</sup>, a period consisting of 53 days, the system was either non-operational or partially operational for 24 days and Tetra Tech personnel were onsite 30 days. During this time period, the following components were replaced/installed due to the electrical surge:

- Permeate Tank Pressure Transducer
- Upgraded communications transmitter for internet service
- Well PLC Input Module
- Main PLC Module
- VFD Pump Controller (swapped with onsite spare)
- HMI Unit
- Network Switches, Cables, and Router

- Main PLC Output Module
- Fiber Optic Network Module at Well and Plant
- Main PLC Module (Exchanged for warranty replacement)
- Allen-Bradley Power Supply
- Allen-Bradley Main PLC Chassis

The repair work following the lightning damage was extremely challenging due to the complexity of how the component failures manifested. The exact circumstances of the communication stoppages were rarely repeatable and generally were random. Following a repair, the system would often operate for a period of time (varying from hours to days) without incident but then would unexpectedly fault again. With each repair, it appeared the issues had been resolved, only to have a fault or communications failure cause the RO unit to shut down again. The work that Industrial Systems was conducting over the internet required Tetra Tech personnel to physically be onsite to monitor the system and perform physical tasks and testing needed to troubleshoot the system and complete the repair work.

## **System Maintenance Not Completed in 2019**

The 2019 Year 12 water treatment statement of work included a line item (Subtask 4C) for the replacement of RO system butterfly valves. This work was not completed in 2019 as it was deemed low priority when compared to unexpected costs associated with the August 11, 2019 lightning strike and subsequent communications issues.

## **Recommendations and Discussion**

Tetra Tech is making the following recommendations for future Beal RO water treatment plant operations:

### [Remove or Reconfigure Valve YV125A](#)

Tetra Tech recommends the removal or reprogramming of the “bypass” valve identified as YV125A. The purpose for the valve in the originally designed system was to return a portion of the 1st pass permeate back into 1st pass feed, which reduces influent contaminant concentrations and helps balance feed pressures between 1st and 2nd pass arrays.

Thirteen years of operating the RO system has resulted in higher contaminant concentrations in the leach pad influent. The degrading water quality has reduced the RO system capacity and has resulted in an opposite flow path through the YV125A valve (raw water is now being pushed through the valve into the 2nd pass feed waters). The problem was further exacerbated in 2019 when the 2nd pass membrane elements were replaced and the aging 1st pass elements were not able to supply adequate water to the 2nd pass of the system. This condition will shorten the life of the newly purchased second pass membranes and increase the possibility of a mass precipitation event in the 1st pass of the system, especially if the system is operated at higher production levels.

YV125A valve replacement will require rebuilding significant portions of the 1<sup>st</sup> and 2<sup>nd</sup> pass feed plumbing and will also require a new Variable Frequency Drive (VFD) controller for the 2<sup>nd</sup> pass booster pump. Alterations to the system PLC/SCADA programming will also be necessary. Tetra Tech is currently in the process of identifying the available options and costing where possible.

### [Replace First Pass Membrane Elements](#)

The 1<sup>st</sup> pass consists of 2-stages; stage 1 includes the “A” and “B” Arrays with 4 vessels in each array containing 6 elements per vessel for a total of 48 membrane elements, and stage 2 consists of the “C” Array with 4 vessels containing 6 elements per vessel for a total of 24 membrane elements. In 2009, all 24 of the “C” array membranes were replaced due to significant scaling. In 2012, all 72 of arrays “A”, “B” and “C” membrane elements were replaced due to with severe scaling, and in 2015, 27 membrane elements were replaced in Arrays “A” and “B” in various locations due to significantly higher than average element weights.

Tetra Tech recommends the replacement of all 72 1<sup>st</sup> pass RO membrane elements in order to maximize the production of 2<sup>nd</sup> pass permeate water, reduce the level of solution in the Beal heap leach pad, extend the life of the new (2019) 2<sup>nd</sup> pass membrane elements, and provide a new operational baseline (point of comparison for operational adjustments) reflective of the current raw water conditions.

#### [Replace Media in MMF Vessels 100, 200, and 300](#)

The media material in the Multi Media Filters (MMF's) has not been changed since the construction of the RO system in 2008. The media consists of a gravel layer which covers the underbed plumbing, a 3-inch thick garnet sand layer, a 24-inch thick greensand layer, and a 12-inch thick anthracite layer. Testing of the media in 2016 identified that the greensands are no longer functioning, and that pretreatment media has generally degraded in size which reduces flow capacity, filtering efficiency, and backwash effectiveness through the media.

Tetra Tech RO experts have reviewed laboratory and operational data from the past few operational seasons and have concluded that the greensand media is no longer needed in the MMF configuration due to the Total Iron, Ferrous Iron, and Manganese complexation with cyanides.

Tetra Tech recommends replacing the original media with different products that will provide greater filtering capacity and increased flow capacity. This is especially important because replacement of the 1<sup>st</sup> pass membrane elements and removal of the bypass valve YV125A will necessitate maximum 1<sup>st</sup> pass production which in turn requires achieving the original design raw water feed flow through the MMF's.

#### [Replace RO SCADA Computer and Upgrade Software](#)

Tetra Tech recommends the replacement of the SCADA computer and associated system software. The current computer uses Microsoft Windows 7. During 2019, Microsoft reduced support for Windows 7 and will completely discontinue support in June of 2020. The Microsoft action has led other windows-based software manufactures, such as the WonderWare used by the SCADA program and the Rockwell software utilized by the Human Machine Interface (HMI), to stop support of their software versions for the Windows 7 operating system as well. In addition, the Beal RO SCADA computer has operated in extremely challenging conditions including dirty/dusty air, high humidity, and several plumbing failure events which resulted in complete saturation of the machine. These conditions have resulted in unstable computer operations and increased potential for cyber-attack.

#### [Mid and End of Season Cleanings](#)

Routine RO membrane maintenance is required to optimize the life span of membrane elements, deliver efficient RO operation, and minimize system pressures which will prolong the life of other system components such as pumps and valves. Membrane maintenance includes the practice of "soaking" elements, permeate rinses with CIP, and chemical cleaning. Historically, the Beal RO elements received an end-of-year cleaning and occasionally, when production rates were high, a mid-season cleaning as well. Due to the concentration of contaminants in the solution being treated at the Beal RO water treatment plant, Tetra Tech strongly recommends membrane elements undergo periodic permeate soak events along with a mid and post season cleaning. The midseason cleaning will be utilized to remove accumulated foulants which will maximize membrane life, membrane operational efficiencies, and reduce operational pressures. Every RO system is different and faces a unique cocktail of constituents to remove during the cleaning process, making an exact protocol for chemical usage and cleaning procedure impossible to generically template. However, Tetra Tech continues to identify and develop procedures which are tailored to the Beal site since the CIP purchase in 2017.

The post season cleaning should include the additional step of membrane preservation by pumping a 1% sodium metabisulfite (by weight) solution through the system which is required for proper storage of the membrane elements.

### *Dedicated CIP Equipment Area*

Tetra Tech recommends the construction of a dedicated area within the existing RO building for operation and storage of the CIP system. This approach would greatly reduce hazards (Slips, Trips, and Falls) created by hoses connecting the CIP (currently in Connex storage container) and the RO system as well as hazards associated with ice formation on walking surfaces during cleaning operations conducted during the latter portions of the season. Additionally, relocation of the CIP system would allow for safe working space when adding chemicals to the CIP system.

### *Remove Permeate Storage Tank Cover and Clean Tank*

2<sup>nd</sup> pass permeate water from the RO system is transferred into a large steel Freshwater Storage tank located just north of the RO building. The tank was originally part of the Beal Mountain Mine operation and was incorporated into the RO operations to provide surge and storage capacity for RO operations including the ability to provide water for membrane flushing and cleaning operations, both of which require extremely clean water (i.e. 2<sup>nd</sup> pass permeate) in order to be efficient and prevent further damage to the membrane elements.

During mine operations, an insulated ceiling was installed on the tank which consisted of placing sheet Styrofoam and oriented strand board (OSB) over openings at the top of the tank. The OSB is now degraded and large pieces have been blown off or fallen into the tank from the roof. The debris in the tank can be problematic because it can block the transfer pump outlet and fouls the permeate water needed during membrane maintenance activities.

Tetra Tech recommends removing the remaining roofing material. Additionally, Tetra Tech recommends accessing the tank interior and pressure washing the lower portions of the tank to remove debris.

### *RO System Butterfly Valve Replacement*

Tetra Tech recommends that butterfly valves in the RO system be replaced prior to the start of the system in 2020. The valves are an important component in the RO system and utilized to divert process waters within the system when in operation as well as isolate portions of the system during various cycles of RO operations. All of these valves are original to the system and have reached the end of their operational expectancy. At least two of the valves were identified as allowing fluid to pass while in the closed position while performing system check valve inspections and replacement activities in 2018.

### *Freshwater Pond Level*

Results of the 2019 investigation identified numerous compromises in the liner material of the Freshwater Pond. Tetra Tech recommends the Upper Pond be kept as low as operationally possible during the 2020 water treatment season to minimize the quantity of water that may be entering the groundwater system in that area.

## REFERENCES

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## APPENDIX A – WATER LABORATORY ANALYSIS

## APPENDIX B – 2019 OPERATIONAL FIELD DATA

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**To:** Sonny Thornborrow, US Forest Service

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**From:** Randal English

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**Date:** May 28, 2020

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**Subject:** Yearly Operations Summary – 2019 Beal Year 12 RO Treatment Season

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**Contract:** GS-00F-168CA (Order 12034319F0152)

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Tetra Tech is pleased to submit this Yearly Operations Summary – 2019 Reverse Osmosis (RO) Year 12 Water Treatment Season for the Beal Mountain Mine located 16 miles west southwest of Butte, Montana, in Silver Bow County. This yearly report is required as a deliverable for Task 6 of the Beal Mountain Mine Year 12 Work Order. Data reported includes water volumes treated through the RO Treatment System, heap leach solution level monitoring, and heap leach laboratory and field solution chemistry analytical results.

### **TOTAL LEACH PAD SOLUTION VOLUME TREATED BY RO**

The Beal RO Water Treatment system activities began May 3, 2019 with the restoration of power to the site following snow removal. On May 14<sup>th</sup> Tetra Tech mobilized to the site and began assembling the RO plant and began circulating from the extraction sump (Sump-1) to the reject sump (Sump-3A) in order to clean any accumulated scale from the pipes and begin blending the stratified (presumably) leach pad solution. Full mobilization efforts began on May 17, 2019, with the mobilization of membranes to the site and subsequent plant assembly. The RO system was started on May 30, 2019, and full-scale water treatment began on May 31<sup>st</sup> following minor system repairs. Minor system repairs included pressure gauge checks, pressure transducer calibration, meter calibration, and addressing a non-functioning transducer on the Fresh Water Storage Tank.

At startup, the water treatment totalizer meter reading was reset to zero (0) gallons. The Year 12 contract called for the RO System to produce 18 million gallons of treated water. A contract modification (Mod #1 dated August 28, 2019) authorized the production of an additional 4 million gallons of treated water. The treatment season ended October 14, 2019, with the plant 2<sup>nd</sup> pass permeate (treated water) meter reading 22,006,682 gallons. This is the actual treatment volume for the Year 12 water treatment season. Total treated water produced to date is 234,932,106 gallons.

Heap leach solution elevation in Sump 1 was measured on May 9<sup>th</sup>, 2019 at 7491.45 feet; the solution elevation at the end of the treatment season on October 14<sup>th</sup>, 2019 was 7,482.26 feet.

### **BEAL RO SYSTEM OPERATIONS**

The multi-stage, semi-permeable membranes are the primary contaminant removal component of the Beal Mountain RO system. A membrane functions when influent water is supplied to the membrane surface at a pressure greater than the osmotic pressure of the solution being treated. This creates a significant pressure differential across the membrane, forcing water molecules through the membrane. The pore size on the membranes restrict the passage of impurities, bacterium, and ions larger in size than the pores of the membrane. The solution that passes the membranes is called “permeate”, the remaining solution is referred to as “reject”.

The concentration of contaminants in the solution being treated dictates the operating pressure on the membranes. A higher contaminant load requires higher operating pressure due to the higher osmotic pressure exerted by the water and the dissolved solutes. When operating at elevated pressures, the system must be closely monitored to avoid damaging the membranes. Damage can occur when excessive pressure is applied to the membranes and the differential pressure between the feed side and the permeate side becomes too high, so that ions are forced into the membrane pores or the reject water becomes so highly concentrated that it can no longer keep the ions and molecules suspended in solution resulting in precipitate formation. This precipitation forms solid molecules and is often referred to as membrane “scaling” or “fouling”. Significant scaling greatly reduces the operational capacity of a membrane element, as well as the overall life cycle of a membrane. Meticulous attention must be paid to operational parameters and diligent system adjustments must be made to prevent catastrophic scaling from occurring when operating RO systems near the upper limits of their design capacities, such as the scenario at the Beal RO plant. To operate at the upper limits of design, the amount of permeate needs to be reduced in order to keep solution concentrations in the reject below the point of mass precipitation.

Regular membrane cleaning regiments can be employed to remove minor amounts of scale and fouling. One of the membrane cleaning options include “soaking” the RO membranes (1<sup>st</sup> Pass, 2<sup>nd</sup> Pass, or Both) in 2<sup>nd</sup> pass permeate water (treated water). This process involves pumping stored 2<sup>nd</sup> pass permeate water into the membrane vessels while monitoring the Specific Conductance (SC) of the reject water. Permeate water is pumped into the vessels until the SC measurements of the reject water from those vessels are observed to be at or near the SC values of the water being pumped in. The membrane elements are then allowed to soak in the clean water for approximately 18 to 24 hours. This allows salts and other dissolvable constituents, along with micro fine particulates, to be removed from the membrane surfaces and pore spaces, improving membrane efficiency and reducing the probability of a mass scaling event to occur. The practice of “soaking” the membranes is widely accepted amongst water treatment professionals and is highly recommended by Tetra Tech’s RO experts who are familiar with the current RO configuration and have evaluated the chemical constituents of the Beal RO raw water. Another membrane cleaning option utilizes specially formulated chemicals of low pH (2 – 3) and high pH (10 - 11) mixed in solution. The solutions are then pumped and recirculated through each array of the system at a targeted flow and pressure which allows the solution to scour out precipitates and fouling. Both cleaning regiments were employed during the 2019 water treatment season and are further discussed under section Membrane Cleaning below.

## **Beal RO System Operational Efficiencies**

The volume of treated water was monitored and recorded using the Beal RO system computer software data logger. Tetra Tech has calculated an estimated net effective efficiency for the 2019 RO operations by extracting flow data from the RO influent and 2<sup>nd</sup> pass permeate lines (total gallons solution in and total gallons 2<sup>nd</sup> pass permeate out). The data set consisted of extracting flow meter readings (gpm), at sixty-minute intervals, from archived computer data. The entire 2019 treatment season’s influent and 2<sup>nd</sup> pass permeate flow data was then averaged and divided to produce a single estimate of the efficiency at which the RO treats heap leach pad water. In 2019, it is estimated that for every gallon of water entering the RO system, 0.47 gallons of water was produced as 2<sup>nd</sup> pass permeate, as compared to 0.44 gallons in 2018 and 0.39 gallons in 2017. The values calculated are to be considered as estimates because this method does not account for situations where influent water is not fully processed to produce permeate such as while backwashing the Multi Media Filters (MMF’s) or during startup cycles prior to the system coming fully online. The treatment volumes for years 2008 – 2019 are summarized below in **Table 1**.

**Table 1. 2019 Yearly RO Total Treated Water (2nd pass permeate) Summary**

Year	<sup>1</sup> Total Days	Total Gallons Treated (2 <sup>nd</sup> pass permeate)	Average Treatment Rate (gpd 2 <sup>nd</sup> pass permeate)	<sup>2</sup> Approximate Net Effective Efficiency (%)
2008	61	12,007,550	196,845	45%
2009*	119	25,377,606	213,257	46%
2010	130	33,638,532	258,758	44%
2011	147	32,136,432	218,615	46%
2012*	119	24,959,896	209,747	48%
2013	79	13,881,032	175,709	46%
2014	86	14,712,416	171,075	46%
2015*	64	11,295,392	176,491	45%
2016	73	13,188,800	180,668	44%
2017	84	13,500,660	160,722	39%
2018	110	18,227,100	165,701	45%
2019*	98	22,006,682	224,558	47%

\* Indicates year where membranes were replaced. (24 in 2009; 87 in 2012; 27 in 2015; 35 in 2019)

<sup>1</sup> Days of operation were estimated utilizing archive data from RO computer. Total excludes scheduled maintenance including RO membrane soaking periods.

<sup>2</sup> Based on archive data from Beal RO computer. Data is considered estimated due to being derived from season-long averages of flow streams.

Average 2<sup>nd</sup> pass permeate production rates increased significantly in 2019 with an average daily production rate of 224,558 gallons 2<sup>nd</sup> pass permeate produced. Historic average daily production rates range from 160,722 gallons per day in 2017 to 258,758 gallons per day in 2010. Average 2<sup>nd</sup> pass permeate rates were calculated by dividing the total 2019 2<sup>nd</sup> pass permeate production by the estimated number of full days the plant was in operation, not counting downtime during MMF backwashes or down time during maintenance activities. These production rates should be considered approximate.

The Beal RO system was originally designed for 66% permeate extraction (maximum) through the first pass of the system. That 1<sup>st</sup> pass permeate (66% of original raw) is then sent to the 2<sup>nd</sup> pass of the system where it was designed to extract 90% permeate (maximum) (90% of the 1<sup>st</sup> pass permeate), resulting in a maximum possible net efficiency of 59.4%. This was based on the data collected during the RO pilot project conducted in 2006. The Beal RO water treatment system is currently being operated with 50 – 60% permeate extraction in first pass followed by 60 – 70% permeate extraction in second pass to keep the system pressures at a safe level, prevent equipment damage, and avoid potential scaling. The primary driver for the reduction in the 2<sup>nd</sup> pass recovery is the reverse flow condition present at the YV125A bypass valve. The purpose for the valve in the originally designed system was to return a portion of the 1<sup>st</sup> pass permeate back into 1<sup>st</sup> pass feed, which reduces influent contaminant concentrations and helps balance feed pressures between 1<sup>st</sup> and 2<sup>nd</sup> pass arrays. Thirteen years of operating the RO system has resulted in higher contaminant concentrations in the leach pad influent. The degrading water quality has reduced the RO system capacity and has resulted in an opposite flow path through the YV125A valve. Raw water is now being pushed through the valve into the 2<sup>nd</sup> pass feed waters which

degrades the 1<sup>st</sup> pass permeate water quality. This results in the Beal RO system being operated between 43% and 51% net efficiency. The data presented in **Table 1** above was derived through collecting “snapshots” (once every sixty minutes) of flow rates and averaging them into a single number; therefore, it is an approximation which does not account for system operational variability.

## Beal RO System Operational Availability

The RO system availability is summarized in **Table 2** and is further described below.

**Table 2. RO Treatment System Availability Summary**

Date	Cause of Shutdown	Duration
06/11/2019	Low Power Quality	~ 0.2 Day
06/22/2019 – 06/24/2019	System shutdown for membrane soak	~ 3 Days
07/06/2019	Low Power Quality	~ 0.75 Day
07/09/2019 – 07/10/2019	Low Power Quality	~ 1 Day
07/13/2019 – 07/14/2019	Low Power Quality – T-storm	~ 1 Day
07/31/2019 – 08/05/2019	Membrane soak and Mid-Season Cleaning	~ 5 Days
08/07/2019	RO Surge Tank Pump Impeller	~ 0.5 Day
08/11/2019 – 08/15/2019	Low Power Quality – lightning strike; multiple communication losses and Programmable Logic Controller (PLC) faults; membrane soak while system down	~ 5 Days
08/19/2019	PLC/Supervisory Control and Data Acquisition (SCADA) Communication issues	~ 0.25 Day
08/20/2019	PLC/SCADA Communication issues	~ 0.25 Day
08/25/2019	PLC/SCADA Communication issues	~ 0.25 Day
08/27/2019 – 09/04/2019	PLC/SCADA Communication issues; membrane soak while system down	~ 8 Days
09/09/2019	PLC/SCADA Communication issues	~ 0.5 Day
09/14/2019 – 09/15/2019	PLC/SCADA Communication issues	~ 1.5 Day
09/17/2019 – 09/18/2019	PLC/SCADA Communication issues	~ 0.75 Day
09/23/2019	Low Power Quality	~ 0.2 Day

09/25/2019 – 10/02/2019	PLC/SCADA Communication issues; membrane soak while system down	~ 7.75 Day
10/09/2019 – 10/10/2019	PLC/SCADA Communication issues and frozen pipes	~ 1.75 Days

During the 2019 treatment season, there were numerous unanticipated shutdowns of the RO system due to power quality issues, PLC communications issues (following lightning strike), and mechanical failures.

#### **1<sup>st</sup> Shutdown – Low Power Quality**

Tetra Tech arrived on-site on June 11<sup>th</sup> following notification from the RO system that the unit was down. It was determined that the system shutdown was caused by a “Low Power Quality” fault likely due to a power bump rather than full loss of power.

#### **2<sup>nd</sup> Shutdown – Operator initiated Shutdown for Membrane Soak**

The RO system was intentionally shut down on June 21<sup>st</sup> for a 48-hour membrane soak. Second pass permeate was pumped through 1<sup>st</sup> pass (both stages) and 2<sup>nd</sup> pass (all 3 stages) utilizing the clean in place (CIP) system at the flow and pressure recommended by the element manufacturer. The system was restarted June 24<sup>th</sup>.

#### **3<sup>rd</sup> Shutdown – Low Power Quality**

Tetra Tech arrived on-site on July 6<sup>th</sup> following notification from the RO system that the unit was down. It was determined that the system shutdown was caused by a “Low Power Quality”, low voltage fault at the RO plant and a well fault on the frequency drive at the well head, which was most likely due to a brief systemwide power loss. The system was restarted on July 6<sup>th</sup>.

#### **4<sup>th</sup> Shutdown – Low Power Quality**

Tetra Tech arrived on-site on July 10<sup>th</sup> following notification from the RO system that the unit was down. It was determined that the system shutdown was caused by a “Low Power Quality”, power failure. The system was restarted on July 10<sup>th</sup>.

#### **5<sup>th</sup> Shutdown – Low Power Quality**

Tetra Tech arrived on-site on July 14<sup>th</sup> following notification from the RO system that the unit was down. It was determined that the system shutdown was caused by a “Low Power Quality” fault likely due to a power bump rather than full loss of power. The sensitivity of the power sensor was slightly reduced, and the system was restarted.

#### **6<sup>th</sup> Shutdown – Operator initiated Shutdown for Membrane Soak and Mid-Season Cleaning**

The RO system was intentionally shut down on July 31<sup>st</sup> for a 24-hour membrane soak prior to the start of the mid-season cleaning. The precleaning soak was utilized to enhance the effectiveness of the cleaning chemical used during the midseason cleaning through removal of dissolvable constituents and micro fine particulates. Upon completion of mid-season cleaning activities, several maintenance items were undertaken including removal and repair of a stainless-steel pipe manifold and the fabrication and installation of the replacement 1<sup>st</sup> pass reject valve. The system was restarted on August 5<sup>th</sup>.

#### **7<sup>th</sup> Shutdown – RO Surge Tank Pump Failure**

Tetra Tech arrived on-site August 7<sup>th</sup> following notification from the RO system that the unit was down due to a “Remote Run Disable” alarm. Tetra Tech personnel began troubleshooting the system to identify the source of the alarm which is generic to any unexpected condition controlled by the desktop SCADA. Final diagnostic of the alarm determined that the RO Freshwater Storage tank (permeate tank) had been filled to the failsafe limit set in the SCADA due to a failure of the pump impeller on the tank discharge pump. The failed pump and motor were

removed from service and a spare unit was retrofitted to temporarily work in its place. Additionally, during the shutdown Tetra Tech personnel initiated a manual flush of the 1<sup>st</sup> pass membranes to ensure the thorough removal of raw and concentrate waters. During the flush cycle, a 2-inch fitting failed on the flush pump and began spraying water throughout the front portion of the RO building. The flush cycle was immediately terminated, and the failed piping was repaired. The manual flush cycle was reinitiated and completed without incident.

### **8<sup>th</sup> Shutdown – Lightning Strike**

On August 11<sup>th</sup>, following severe thunderstorm activity in the area, Tetra Tech personnel checked the operational status of the RO system by remote login to the SCADA system. The system appeared nonoperational and several anomalies were observed on the SCADA computer, however, the system had not initiated the remote notification protocol of automated phone calls. Tetra Tech personnel immediately mobilized to the site and upon inspection, found that the SCADA had identified a low inlet pressure alarm and multiple communication loss faults from various components of the system.

System troubleshooting over the next several days identified burnt circuitry in the Freshwater Storage tank pressure transducer, damaged fuses in both the main PLC cabinet and well head PLC cabinet, fault at the well pump variable frequency drive (VFD) control, fault on the well head flow meter, nonresponsive well head PLC communications module, and burnt circuitry on one of the main PLC input modules at the RO plant. Replacement components were procured, installed, and the system was restarted on August 16<sup>th</sup>.

Tetra Tech personnel continued trouble shooting the system faults and replaced or repaired the observed damaged components as they were identified. The repair work following the lightning damage was extremely challenging due to the complexity of how the component failures manifested. The exact circumstances of the communication stoppages were rarely repeatable and generally were random. Following a repair, the system would often operate for a period of time (varying from hours to days) without incident but then would unexpectedly fault again. With each repair, it appeared the issues had been resolved, only to have a fault or communications failure cause the RO unit to shut down again. The work that Industrial Systems was conducting over the internet required Tetra Tech personnel to physically be onsite to monitor the system and perform physical tasks and testing needed to troubleshoot the system and complete the repair work.

### **Multiple Shutdowns – PLC/SCADA Communication Failure**

During the period of August 19<sup>th</sup> through October 10<sup>th</sup> the system experienced numerous unscheduled shutdowns. Table 2, above, provides a synopsis for the frequency and approximate duration of system shutdowns and failures which continued to plague the Beal RO PLC and SCADA network following the August 11<sup>th</sup> event.

Shutdown durations ranged from a few hours up to 8 days. With the exception of a short duration shutdown on September 23<sup>rd</sup> due to a power quality issue, all shutdowns during this period were associated with ongoing electronic system communication issues as a result of the lightning strike on August 11<sup>th</sup>. During this period, Tetra Tech replaced the following components: multiple PLC and input modules in the main PLC cabinet, main PLC rack and power supply, Human Machine Interface (HMI) screen, network router, all network switches, most ethernet cables, added necessary hardware to isolate internal system communications from the internet by routing through a designated fiber optic line. Repair of the system was further complicated by the fact that finding replacement components was found to be especially challenging due to the “age” of the Beal RO unit. At 12-years in operation, the hardware platform of the PLC’s, Human Machine Interface (HMI), and communications systems are no longer manufactured or supported. The replacement components were procured through Industrial Systems and were generally remanufactured or factory certified used stock and were located through various vendors and suppliers. A more detailed progressive analysis is presented in the “Maintenance Tasks Completed During 2019” section of this report.

### Other Minor System Stoppages

Other minor system stoppages occurred during the 2019 treatment season. For example, brief shutdown and restarts needed during PLC programming changes, cartridge filter replacement, or minor maintenance activities. These stoppages did not significantly affect the system operational availability.

It is estimated that the RO system was operationally available 72% of the time during 2019. This rate was calculated based on 137 days of potential full-scale operation (May 31 to October 14) compared with approximately 98 days of actual operation due to the downtimes noted above. Overall, the RO system downtime was minimized due to significant effort by Tetra Tech and its subcontractor (Industrial Systems Inc.).

Historic RO system operational availability has been as follows:

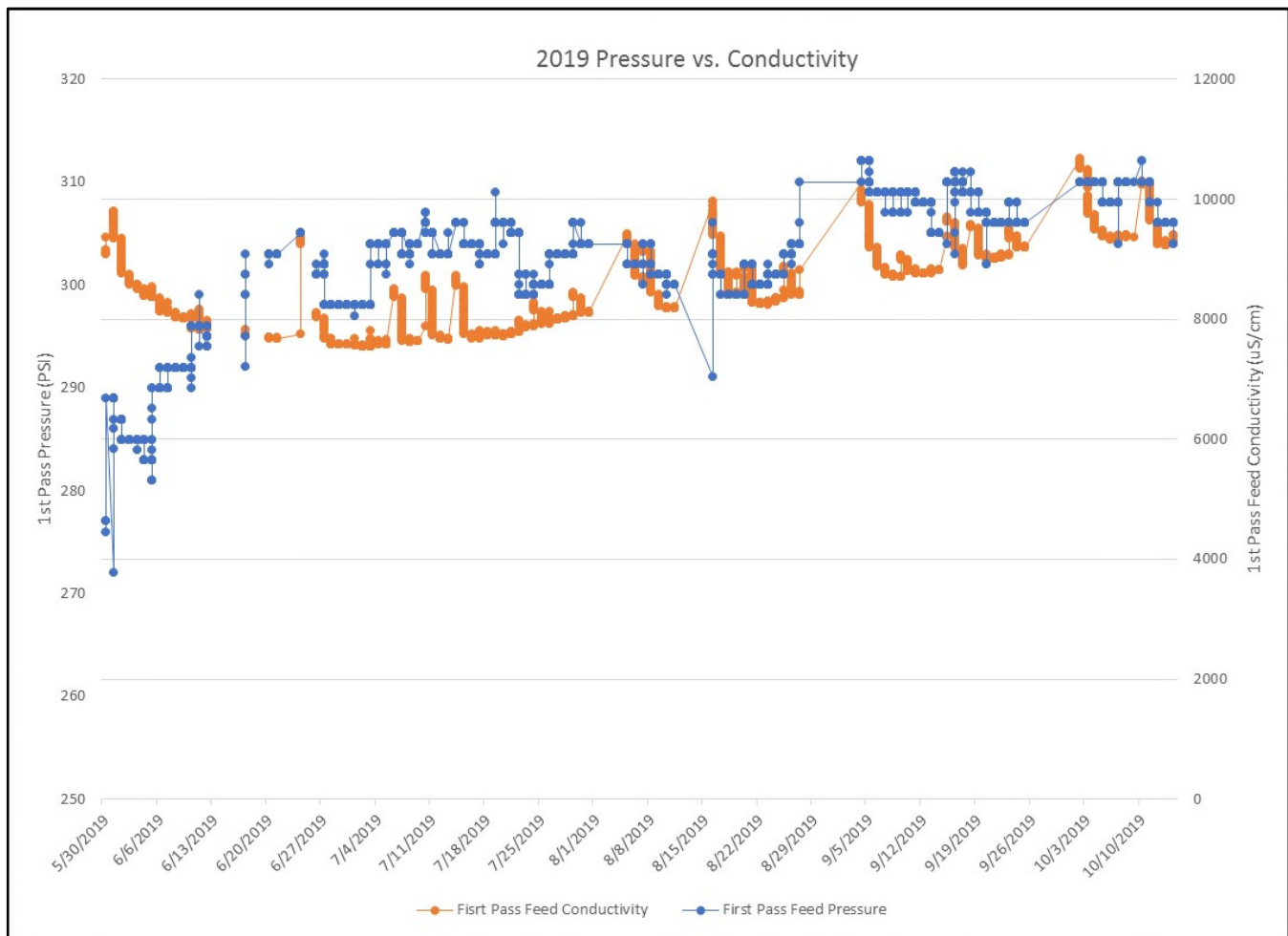
2009 - online 76% of the time  
2010 - online 96% of the time  
2011 - online 97% of the time  
2012 - online 97% of the time  
2013 - online 94% of the time  
2014 - online 91% of the time  
2015 - online 92% of the time  
2016 - online 95% of the time  
2017 – online 95% of the time  
2018 – online 92% of the time  
2019 – online 72% of the time

### BEAL RO SYSTEM WATER QUALITY

#### **General Water Quality**

2019 Beal RO Plant influent water quality was consistent with that observed during previous water treatment seasons. As has been observed in the past, influent water contained elevated Specific Conductance (SC) levels (around 10,000  $\mu\text{S}/\text{cm}$ ) during initial seasonal operation followed by a slow decrease to approximately 7,500  $\mu\text{S}/\text{cm}$  within the first two weeks of operations. During each of the many shutdown periods of 2019, the conductivity would rebound then rapidly decrease upon restart. The longer the shutdown period, the greater the rise in conductivity. This pattern continued throughout the season. A gradual increase in SC was also observed, with an ending value of approximately 9,200  $\mu\text{S}/\text{cm}$  when the plant was shut down on October 14<sup>th</sup>, 2019.

**Figure 1** below illustrates the relationship between 1<sup>st</sup> pass pressures and 1<sup>st</sup> pass (raw water) conductivity where pressure in the 1<sup>st</sup> pass generally increases as water conductivity increases. However, unlike previous treatment seasons where 1<sup>st</sup> pass pressure fluctuations generally coincide with raw water conductivity, pressures at the start of the 2019 treatment season appear lower and increased over subsequent weeks of RO operation, even though the raw water conductivity was initially decreasing. This abnormality was the result of system operational adjustments which were instituted to maximize the 1<sup>st</sup> pass permeate production and minimize the volume of raw water entering the 2<sup>nd</sup> pass feed through the systems balancing line, although these adjustments resulted in higher than normal operating pressures for 1<sup>st</sup> pass (approximately 280 psi in 2018 vs approximately 305 psi in 2019). The elevated flows through the balancing line resulted from the installation of the new second pass membranes which required higher permeate flows (2<sup>nd</sup> pass feed) than the older 1<sup>st</sup> pass membranes could provide. Several smaller spikes in the raw water conductivity can be observed in **Figure 1** which correlate to short term system shutdowns as described in **Table 2** above. Although system adjustments can help alleviate elevated pressures in the RO system, increased raw water conductivity (in general) will cause increases in the RO operating pressures.



**Figure 1 First Pass Pressure Compared with Raw Water Conductivity**

## Laboratory Chemical Analysis

Tetra Tech collected 2 (two) raw influent water samples for analysis according to Table 6 of Tetra Tech's 2012 Reverse Osmosis Water Treatment Plant Sampling and Analysis Plan (WTSAP) (Tetra Tech 2012) during the 2019 treatment season. The first sample was collected during the first week of full-time plant operations (June 6<sup>th</sup>) and the second sample was collected at the end of seasonal RO operations (October 7<sup>th</sup>). Both samples were submitted to Energy Laboratories, Inc. of Helena, Montana, for analysis. Four additional raw influent water samples were collected every other week and submitted for laboratory analysis according to an abbreviated Table 6 of Tetra Tech's 2012 WTSAP. **Table 3** shows the results of the raw influent water samples collected during the 2019 treatment season. Laboratory results are presented in **Appendix A**.

**Table 3. Raw Influent Water Samples**

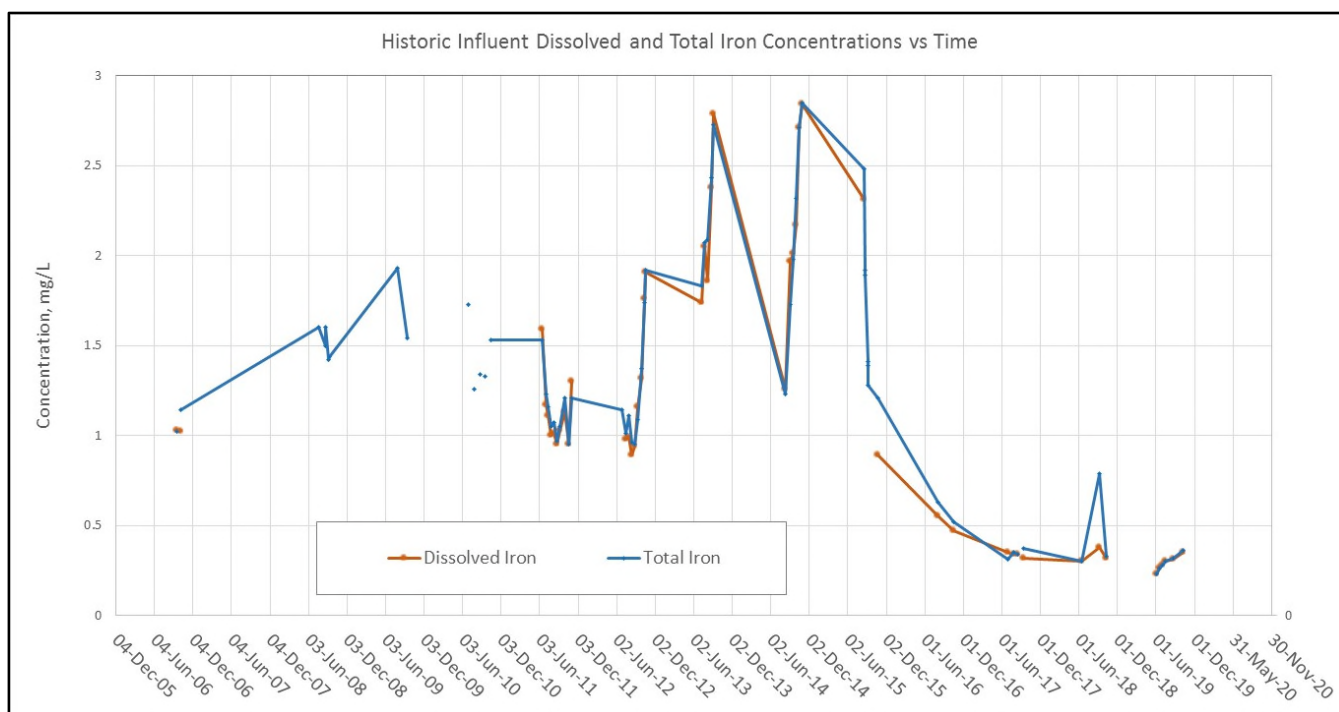
Raw Influent Water Samples	6/6/2019 Start-up	6/20/2019	7/1/2019	7/17/19	8/21/2019	10/7/2019 Shut-down
<b>Physical Properties</b>						
pH (S.U.)	7.7*					7.9*
Total Dissolved Solids (mg/L)	6950	6510	6660	6220	5930	8110
<b>Inorganics (mg/L)</b>						
Thiocyanate as N	4.1					0.69
Alkalinity, Total as CaCO <sub>3</sub>	220	200	210	220	220	210
Chloride	450	447	382	422	472	534
Sulfate	3780	4070	3720	3790	4270	4150
Cyanide, Total	0.5				0.78	0.6
Cyanide, Weak Acid Dissociable	0.004				0.094	0.004
Thiocyanate	1					2.8
Fluoride	0.4	0.4	0.4	0.4	0.3	0.4
<b>Nutrients (mg/L)</b>						
Nitrogen, Ammonia as N	15.3	14.2	14.6	15	17.4	19
Nitrogen Nitrate as N	<0.01	<0.01	<0.01	<0.01	<0.01	
Nitrogen, Nitrate+Nitrite as N	<0.01	<0.01	<0.01	<0.01	<0.01	<0.05
Nitrogen, Nitrite as N	<0.01	<0.01*	<0.01	<0.01	<0.01	0.02
Phosphorus, Total as P	0.08					0.1
<b>Metals, Dissolved (mg/L)</b>						
Calcium	513	510	512	478	497	527
Iron	0.23	0.26	0.28	0.3	0.31	0.35
Magnesium	65	64.2	58.6	56.6	62	74.6
Potassium	20	22	21	21	24	24
Sodium	1510	1510	1460	1510	1660	1820
<b>Metals, Total (mg/L)</b>						
Arsenic	0.197				0.241	0.258
Barium	0.027	0.027	0.026	0.027	0.030	0.035
Cadmium	0.00088				0.0006	0.00090
Copper	0.16				<0.01	<0.01
Iron	0.23	0.26	0.28	0.3	0.32	0.36
Manganese	0.542	0.59	0.59	0.56	0.58	0.62
Selenium	0.023				0.024	0.026
Silicon as SiO <sub>2</sub>	17	18	17.6	17.8	17.7	16.9
Silver	0.0005					<0.0005
Strontium	4.43	4.7	5	4.7	4.9	5.51

\* Analysis performed past recommended hold time

Constituents from the raw water samples were evaluated for concentration changes between the initial sample taken at the beginning of the treatment season and the end of year sample taken prior to system shutdown. Total cyanide increased slightly from 0.5 mg/L to 0.6 mg/L through the season; however, these values were lower than the minimum value observed the 2018 season despite leach pad solution levels being approximately the same. Weak Acid Dissociable (WAD) cyanide also exhibited lower concentrations during the 2019 season ranging from 0.004 mg/L to 0.094 mg/L. Thiocyanate concentrations however, increased over the treatment season from 1 mg/L to 2.8 mg/L, which is similar to values from previous seasons. Alkalinity levels remained stable at approximately 210 mg/L. Chloride level increased from 450 mg/L to 534 mg/L. Total Dissolved Solids (TDS) levels decreased throughout the first half of the season from 6,950 mg/L to 5,930 mg/L then rose sharply to 8,110 mg/L near the end of the season.

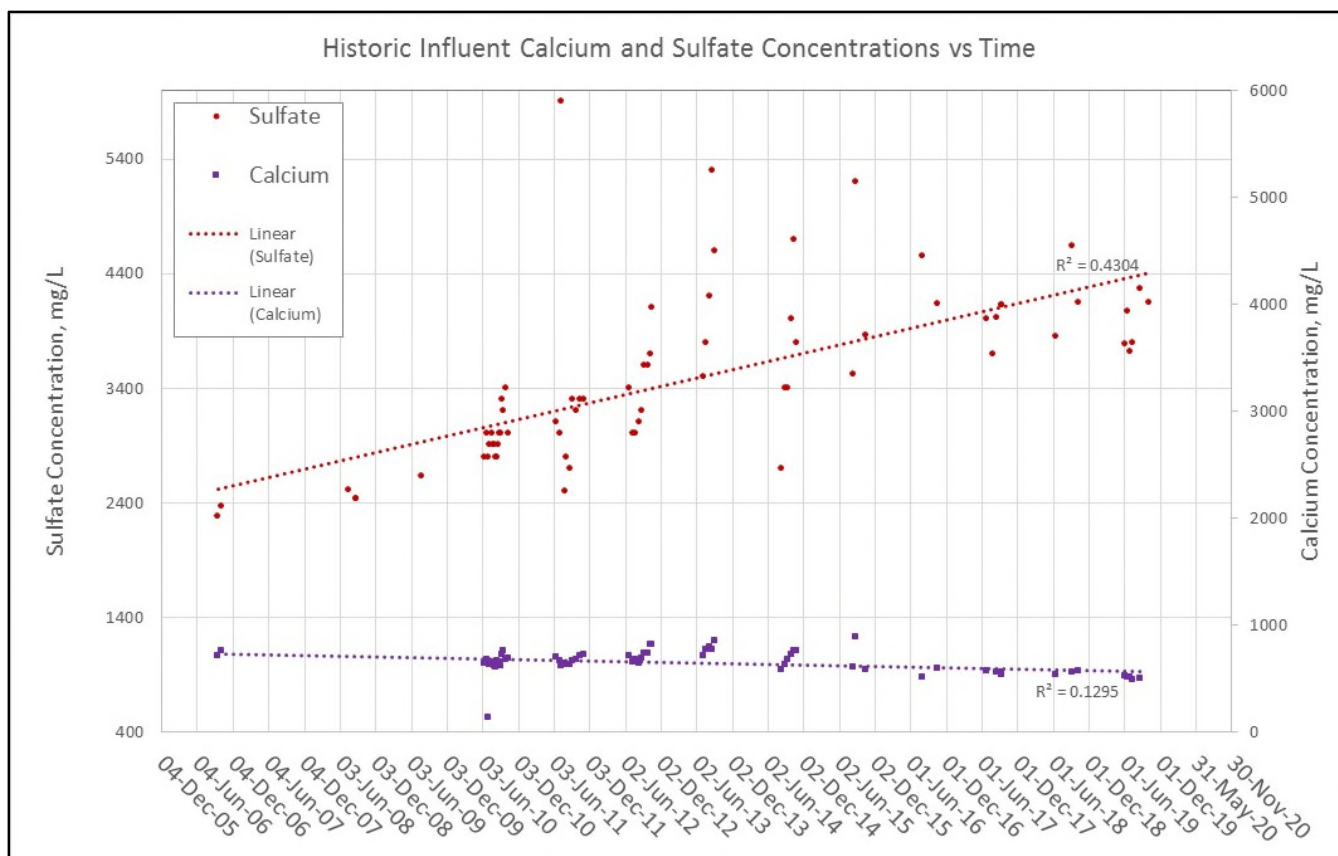
Nutrients remained relatively consistent throughout the treatment season with nitrates and nitrites below the method detection limit of 0.01 mg/L and ammonia ranging from 14.2 mg/L to 19 mg/L.

Dissolved calcium, iron, and magnesium varied slightly throughout the season but generally increased slightly by the end of the treatment season with values ranging from 513 mg/L to 527 mg/L, 0.23 mg/L to 0.35 mg/L and 65 to 64.6 mg/L, respectively. Dissolved sodium increased slightly from 1,510 mg/L to 1,820 mg/L. There were no significant changes in total metals concentrations analyzed over the 2019 treatment season.



**Figure 2. Dissolved and Total Iron Concentrations from 2011 to 2019**

Historic total and dissolved iron concentrations are shown in **Figure 2** above. The data indicates total and dissolved iron concentration values are nearly identical at varying magnitudes of concentration, indicating that most of the iron present in the leach pad is in dissolved form.



**Figure 3. Calcium and Sulfate Concentrations from 2006 to 2019**

Sulfate and Calcium concentrations were also generally consistent with the previous observations. Sulfate varied between 3,720 mg/L and 4,270 mg/L while calcium concentrations varied between 478 mg/L to 527 mg/L. 2018 concentration values for sulfate and calcium in raw water varied between 3,850 mg/L and 4,150 mg/L and 525 mg/L to 569, respectively.

**Figure 3** above illustrates an upward trend in sulfate concentrations of Beal RO raw water since 2006 while calcium concentrations, although with significantly less available data, appears to be trending slightly downward.

Compliance testing for the RO discharge to German Gulch was conducted under the Beal Site Wide Monitoring task. Sampling completed during June was conducted after RO system startup activities but prior to discharge activities and is representative of site conditions without treatment system discharge. During this period, ammonia was below the method detection limit while total cyanide and total recoverable selenium were slightly above their respective chronic aquatic life standards (MDEQ 2019). Selenium and cyanide documented for this period is not associated with treatment system discharge. Additional compliance testing was completed on September 16 during active treatment system discharge as part of Site Wide Monitoring. During this event, all constituents of concern were below chronic-aquatic life standards, and most were below method detection limits.

Laboratory analytic results of all samples collected as part of RO operations during the 2019 treatment season are attached in **Appendix A** and include performance samples associated with cleaning operations.

Results of raw water sampling suggest that leach pad water chemistry did not change significantly over the course of the treatment season.

## Field Tests

Water chemistry tests were performed throughout the 2019 treatment season utilizing field meters and field test kits (Hach®). Samples for field analyses were collected from four locations along the treatment flow path; INF-01 (raw influent water), INF-02 (Post Multi Media Filter (MMF)), 1<sup>st</sup> Stage Permeate (second stage feed), and 2<sup>nd</sup> Stage Permeate (final treated water). The results were recorded and used to analyze the system performance and implement any necessary adjustments to the treatment process. The four monitoring locations are arranged as follows:

- INF -01 (raw influent water) – This monitoring location is used to observe raw influent water pumped from the leach pad prior to being filtered through the MMF's;
- INF-02 (Post MMF) – Monitoring location after MMF's, but before 1<sup>st</sup> stage membrane arrays. Utilized to measure the effectiveness of the MMF's;
- 1<sup>st</sup> Stage Permeate – This monitoring point is on the low-pressure side of the 1<sup>st</sup> stage membrane arrays and before the water enters the 2<sup>nd</sup> stage membrane arrays of the RO system; and
- 2<sup>nd</sup> Stage Permeate – This monitoring point is on the low-pressure side of the final 2<sup>nd</sup> stage membrane array and represents treated water exiting the RO treatment system.

Influent (Raw Water) field conductivity ranged from a minimum of 7,500  $\mu\text{S}/\text{cm}$  on July 1<sup>st</sup>, after the system had been running for approximately 1 month, to its highest value of 9,330  $\mu\text{S}/\text{cm}$  on October 7<sup>th</sup>, resulting in an overall change of approximately 1,830  $\mu\text{S}/\text{cm}$  as compared to a 3,730  $\mu\text{S}/\text{cm}$  change observed during 2018 and 3,143  $\mu\text{S}/\text{cm}$  change observed during 2017.

2018 field-tested chlorine concentrations remained at or just above the method detection limit. Results of laboratory analysis for chlorine degradation by-products were below the method detection limits. Review of both the field and laboratory results suggests the field test kits may be biased high and that in fact chlorine is not present in the raw influent water at measurable concentrations.

## Membrane Cleaning

Prior to the start of the RO unit, several of the first pass membrane elements (first element of each vessel; 4 vessels per array; A, B, and C arrays in 1<sup>st</sup> pass) required cleaning due to observed debris lodged in the feed ends of the elements. The debris included small particulates of precipitated scale, sand-like particles, and other organic debris which had been observed during removal of the elements in the prior year. Membranes of the "B" and "C" arrays were installed just as they had been in 2018. The four (4) elements located at the feed side of the "A" array were reversed and placed in the back end of the vessels so that any debris dislodged would be removed with the waste stream during normal operations. The A and B arrays were then mechanically isolated by replacing the feed manifold which normally distributes feed waters to both arrays simultaneously (see Photo 1 below) with a single feed manifold (see Photo 2 below) and each array was then flushed with the CIP unit so that any debris dislodged would be captured by the CIP filter system.

### Feed Manifold A and B Arrays



Photo 1. RO A & B Arrays manifold feeding both arrays simultaneously.

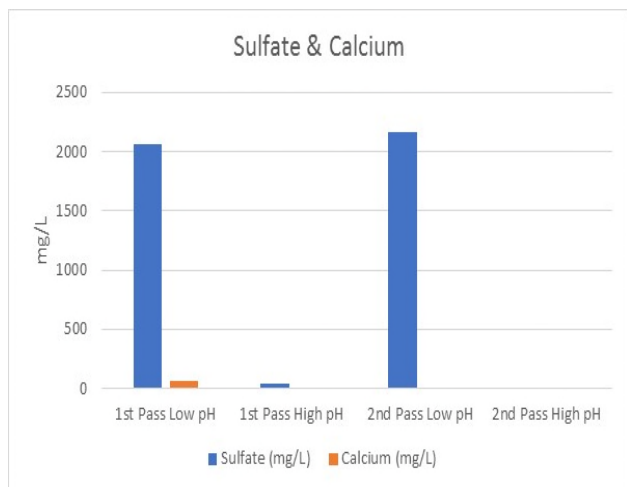


Photo 2. Single manifold placed to feed A or B array independently during cleaning operations.

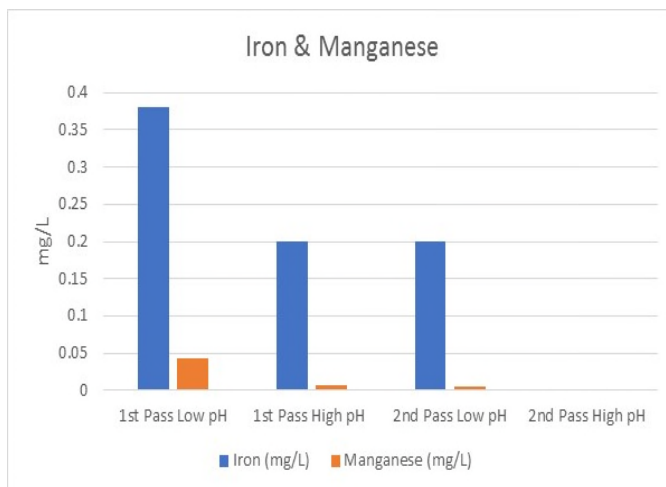
Tetra Tech conducted a mid-season cleaning of the RO membrane elements between July 31<sup>st</sup> and August 5<sup>th</sup>. Cleaning activities were initiated by pumping 2<sup>nd</sup> pass permeate water into each array of the 1<sup>st</sup> and 2<sup>nd</sup> passes of the RO system and allowing the system to soak overnight to loosen particulates and help dissolve precipitates. The CIP skid was then utilized to conduct a two-step chemical cleaning process of low pH solution followed by high pH solution. The first step utilized a cleaning solution of OptiClean™H and RO permeate water. OptiClean™H is a proprietary aggressive low pH, low foaming cleaner formulated to remove metal hydroxides, calcium carbonate, calcium phosphate and other inorganic scale. This product was chosen specifically to combat inorganic fouling that has traditionally been observed on the RO membrane elements and its ability to help reduce gypsum. Cleaning operations included mechanically isolating each array, pumping clean permeate water through each array at a targeted rate of 35-40 gallon per minute per membrane element with a maximum pressure of less than 60 psi. OptiClean™H was then mixed with permeate water in the CIP mixing tank to the concentrations recommended by the manufacture and the solution was recirculated through each array at the targeted rates stated above. Each array was then flushed with clean permeate water until the exiting solution was within 1 pH unit of the raw permeate water. The second cleaning step followed the same process but used a cleaning solution of OptiClean™B. OptiClean™B is a proprietary aggressive high pH, low foaming cleaner formulated to remove organic fouling. After the mid-season cleaning was completed, the system was allowed to soak in clean permeate for 48 hours prior to restarting.

An end of season cleaning of the membranes was performed between October 15<sup>th</sup> and October 18<sup>th</sup>. The cleaning entailed an initial system flush and soak with 2<sup>nd</sup> pass permeate water followed by use of the CIP Cleaning Skid with a low pH cleaner (OptiClean™H) as described above, followed by a thorough rinse with clean permeate water, then a high pH cleaner (OptiClean™B) as described above, followed by a thorough rinse with clean permeate water, and finally, a preserving solution consisting of 1% sodium metabisulfite (by weight) was pumped through the RO elements.

During both the mid-season and end of season cleaning events, samples were collected of the cleaning solution after flushing through the 1<sup>st</sup> pass and 2<sup>nd</sup> pass membranes. **Figure 4** and **Figure 5** below show the concentration of calcium, sulfates, iron and manganese after the cleaning solution was flushed through the membranes. The low pH cleaner seems to be effective at removing calcium and sulfate deposits as well as iron and manganese from the membranes. The high pH cleaner appears to be effective at removing additional iron from the membranes. Laboratory results are presented in Appendix A.



**Figure 4. Calcium and Sulfate Concentration in Cleaning Solution**



**Figure 5. Iron and Manganese Concentrations in Cleaning Solution**

## RO Membrane Maintenance

Tetra Tech conducted two scheduled soak periods as a preventative maintenance measure and three (3) unscheduled opportunistic soak periods during the 2019 operations. The first scheduled soak was completed June 22 through June 24 and the second scheduled soak was July 31 to August 1 just prior to the mid-season cleaning. Three extended soak periods were completed during unscheduled system down time presented in **Table 2** above. These periods included August 11 through August 15, August 27 through September 4, and September 25 through October 2, 2019. Because flow and pressure adjustments to the RO system are required following the soaking periods, improvements to RO membrane performance is difficult to identify when comparing before and after data. However, observations of system fluid conductivity following soaking periods have identified significant increases in SC values. Example: Clean 2<sup>nd</sup> pass RO permeate water (SC≈20  $\mu$ S/cm) is pumped into the 1<sup>st</sup> pass vessels at low pressure. This process is identified as a “flush cycle” because the water is pushed through the membranes at low pressure not intended to generate permeate, therefore, the water flows through the membranes “flushing” the salts and contaminants from the membrane surface and pore spaces. This “flushing” process continues until the first stage discharge (reject flow) SC concentration is approximately equal to 300  $\mu$ S/cm or less. The system is then allowed to soak for a minimum of 18 hours, and, upon re-initiation of a flush cycle, the 1<sup>st</sup> pass discharge waters now have SC values approximately equal to 1,500  $\mu$ S/cm or more, 75-times greater than the water originally pumped into the 1<sup>st</sup> pass vessels.

The Beal RO system was not designed to allow a soaking period for the 2<sup>nd</sup> pass membranes as the quality of the water entering the 2<sup>nd</sup> pass was intended to be clean enough (<300  $\mu$ S/cm) that soaking periods would not be necessary. However, the Beal RO system was designed with a “bypass valve” (valve YV125A) which was intended to allow minor amounts of raw water into the second pass feed stream if needed (such as system

startup) but generally allow excess 1<sup>st</sup> pass permeate to flow back into the 1<sup>st</sup> pass feed stream. In reality, valve YV125A allows raw untreated water (up to 60+ gpm) to flow into the 2<sup>nd</sup> pass feed stream which greatly increases 2<sup>nd</sup> pass feed constituent concentrations and pressures. The divergence from design is believed to be due to increases in raw water constituent chemistry, degradation of the media in the MMF's, and degradation of the 1<sup>st</sup> pass membrane elements. To combat the possible negative effects of this situation, Tetra Tech personnel pumped permeate water into each array of 2<sup>nd</sup> pass utilizing manual valve overrides during each soak event or periods of extended downtime.

At the end of the 2019 treatment season, the RO membrane elements were cleaned utilizing the CIP system (as discussed above), preserved with a 1% sodium metabisulfite (by weight) solution, and removed from the Beal RO system. Upon removal from the RO unit, each membrane was drained of excess solution, and a year-end inspection consisting of physical examination for signs of scaling or other damage of each membrane was performed. Each membrane was then placed in a new storage bag with both ends heat-sealed closed to protect the membrane element from drying out during storage. The 1% sodium metabisulfite solution is utilized to inhibit microbial growth during long term storage.

## RO Membrane Performance Normalization

Membrane performance in RO operations can be evaluated through a variety of data tracking and calculated parameters. Standard calculated parameters for RO systems in the industry often include differential pressures, net driving pressures, normalized permeate flows, salt passage or rejection, differential pressure drop coefficient, and permeability. Tetra Tech collected a variety of data throughout the 2019 operational season in order to calculate several of the parameters listed above. However, utilizing these parameters for membrane performance for the Beal RO system is difficult to evaluate in detail due to the following:

- Frequent system downtime – Beal RO system downtime, even for short periods of time, results in increased feed solution constituent concentrations (increased SC values) followed by a general downward trend in concentrations as exhibited in the 1<sup>st</sup> Pass Conductivity shown in Figure 1 above. Although these increases in SC are consistent in occurrence, they are not consistent in magnitude, duration, or the subsequent decrease. These observations are consistent with observations from previous years operations and is suspected to be the result of stratification of solution in the Beal leach pad and can result in data volatility.
- Operational adjustments – Operational adjustments to the Beal RO system are routinely performed to maintain appropriate flows and pressures and are often dictated by variations in the feed solution constituent concentrations. Adjustments of the Beal RO system can include feed water flow and pressure for 1<sup>st</sup> and 2<sup>nd</sup> passes, reject solution flow and pressure for 1<sup>st</sup> and 2<sup>nd</sup> passes, and leach pad well solution flow and pressure. Change to flow or pressure at any one of these locations can result in data volatility.
- Equipment calibration – Flow meters, SC meters, and pH meters require frequent checks and calibrations. Most calibration adjustments tend to be minor (less than 1% of display value) but those adjustments can skew data results.
- Variable feed solution constituent concentrations – Feed solution concentration to the RO system varies throughout the season. Decreases, as observed during early season operation, or increases in constituent concentrations due to down time or late season operations, trigger manual system adjustments to maintain appropriate flow and pressures in the system.
- Deteriorated condition of the 1<sup>st</sup> pass concentrate valve and 2<sup>nd</sup> pass feed valve.

Tetra Tech personnel collected specific data during the 2019 operational season to evaluate and optimize RO operations at the Beal Mountain site. The data collected included conductivity and pressure data for both feed and reject stream flows for each individual array of the RO system (1<sup>st</sup> Pass – 1<sup>st</sup> Array, 1<sup>st</sup> Pass – 2<sup>nd</sup> Array, 2<sup>nd</sup> Pass- 1<sup>st</sup> Array, 2<sup>nd</sup> Pass- 2<sup>nd</sup> Array, and 2<sup>nd</sup> Pass- 3<sup>rd</sup> Array). The data collected must then be “normalized” which is a technique used to evaluate if changes in flow or rejection are most likely caused by membrane fouling, membranes degradation, or just due to changes in operating conditions (Lenntech, 2001). The data can help to

determine cleaning regiments, chemical feed rates, and general system adjustments to help reduce the likelihood of creating conditions in the RO system which could lead to mass fouling of the elements.

Overall, the following system performance metrics suggest possible fouling of the 1<sup>st</sup> pass membranes during the early part of the season followed by improved performance latter in the season.

### Net Driving Pressure

The data collected was utilized to calculate Net Driving Pressure (NDP) which is essentially the sum of all forces acting on the membrane. These may include pump or feed pressure; back pressure from line restrictions and storage tank; and osmotic pressure of the feed and permeate waters. The net driving pressure is the measure of the actual driving pressure available to force the water through the membrane. As net driving pressure increases, the flux (permeate production) increases proportionally (given all other factors are held constant).

The average NDP<sub>a</sub> was calculated utilizing the following equation:

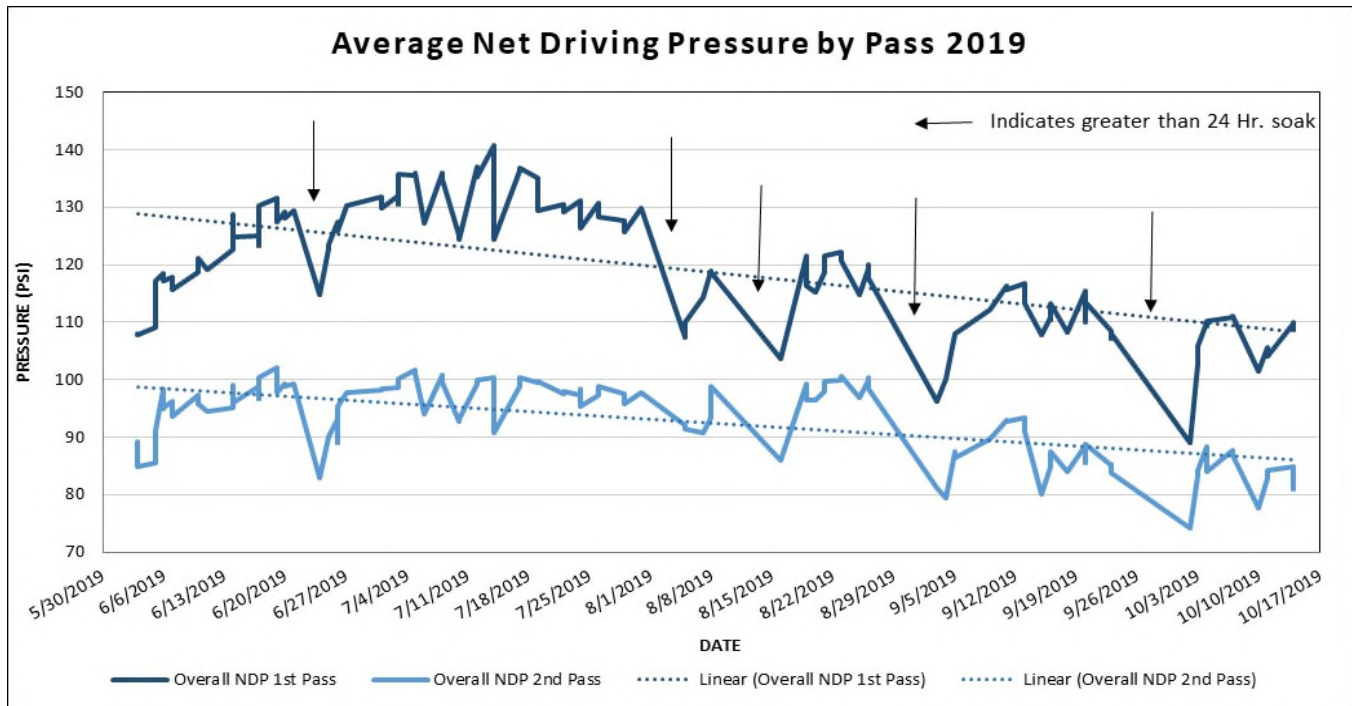
$$NDP_a = P_f - P_p - P_o$$

Where	NDP <sub>a</sub> = Average Net Driving Pressure
	P <sub>f</sub> = Average Feed Pressure (average of feed and concentrate pressures)
	P <sub>p</sub> = Pressure in the permeate line (gauge pressure)
	P <sub>o</sub> = Average Osmotic Back Pressure of feed water (average of feed and concentrate salt concentration divided by 100)

Generally, P<sub>o</sub> is calculated utilizing Total Dissolved Solids (TDS) values; however, for the Beal RO Plant this data is calculated utilizing the plant Specific Conductance (SC). This is done for convenience as plant in-process meters measure SC and because analysis of historic field data collected indicates that the relationship between SC and TDS is generally consistent.

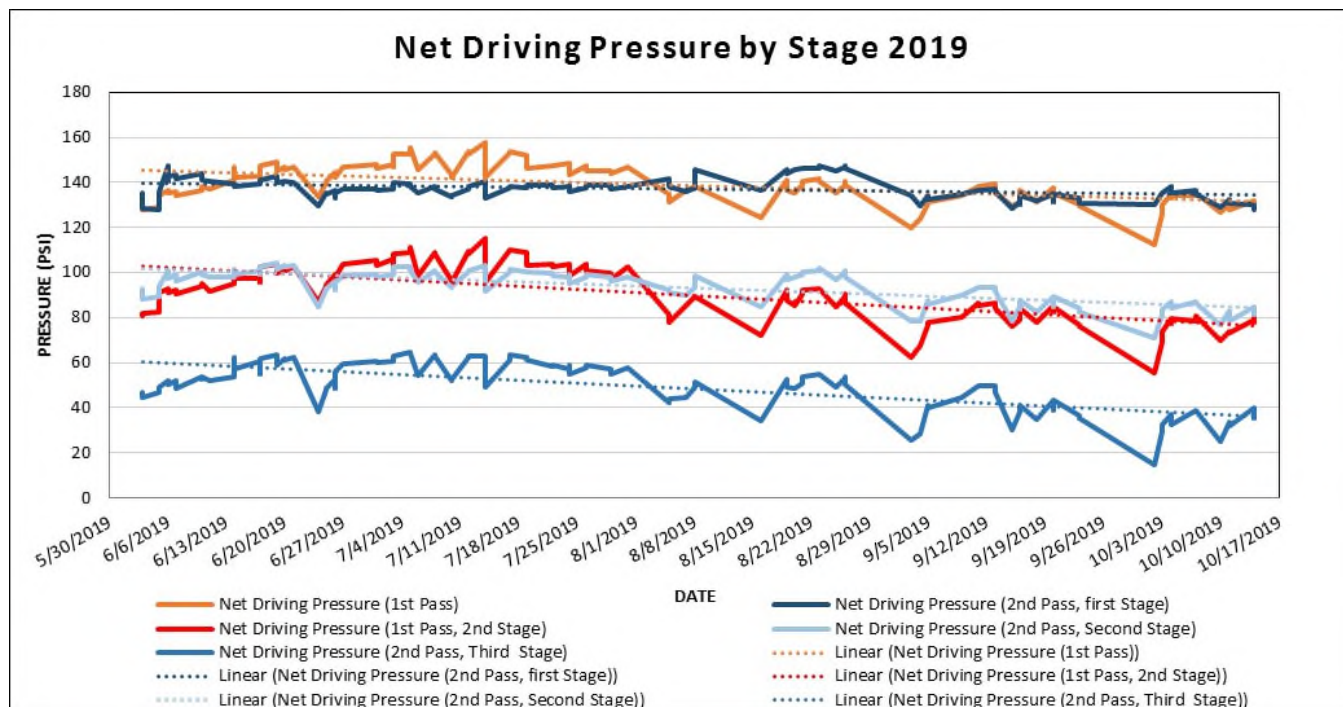
The NDP will begin to increase over time due to fouling or scaling of the RO membranes and it is common practice in the industry to instigate a membrane cleaning regiment when NDP increases by 15% to 25% above baseline value. Volatility and significant decreases in NDP can be due to variances in instrumentation (calibration of meters), errors made during data collection, significant system adjustments on nonautomated RO operations (such is the case a Beal), or influence from effective cleaning or soaking events.

When NDP is monitored for each stage of a RO system, problems can be identified between fouling and scaling based on the location of increases in pressure. An increase in NDP in the front stage of a RO indicates possible fouling issues while increases in NDP in a second stage indicates scaling. In general, average NDP increased over the first month of operation during the 2019 season then generally decreased during the second half of the operational season, ending at approximately the same value as at startup (**Figure 6**). **Figure 7**(below) displays NDP data for each array of the Beal RO system.



**Figure 6. Average Net Driving Pressure**

A slight overall increase in NDP would be expected in normal RO operations, particularly where systems are being operated near the upper limits of capacity for feed water chemistry, such as the case with the Beal RO system. The decreases in NDP throughout the second half of the season correlate with the mid-season cleaning (completed 08/05/2019) and the frequent system downtime which were used as soak events. It would appear that any fouling or scaling that may have occurred during the early season was removed by the midseason cleaning and that the frequent soak events resulted in minimal or no net accumulation of membrane fouling during the 2019 season. Additionally, the data tends to suggest that extended soaking periods can be nearly as effective as the cleaning events.



**Figure 7. Average Net Driving Pressure by Pass and Stage**

As stated above, evaluation of this type of data is complicated due to the everchanging feed water chemistry which results in continual system adjustments in order to maintain the appropriate flows and pressures. For most RO systems, feed water chemistry is generally consistent, so frequent system adjustments are not required which results in a much smoother graph.

Tetra Tech plans to continue the collection of RO data for the NDP calculation during future operations in order to develop better baseline data and the development of RO membrane cleaning protocols. Plant field data and the resulting calculated values for NDP are presented in **Appendix B** – Tables 1 and 2.

### Normalized Permeate Flow

The data was also utilized to calculate Normalized Permeate Flow (NPF) which is a comparison of RO permeate flow in the present operational conditions to the baseline permeate flow. The purpose of flow normalization is to account for variable input parameters such as net driving force and temperature, both of which have tremendous effect on permeate flows. The effect of these parameters is “normalized” to properly analyze the membrane performance.

Once NDP has been determined, NPF may be calculated based on NDP and temperature using the following equation:

$$NPF = \frac{(TCF \text{ today } ^\circ F) \times (NDP \text{ startup (PSI)}) \times (Permeate \text{ Flow (GPM)})}{(NDP \text{ today (PSI)}) \times (TCF \text{ startup } ^\circ F)}$$

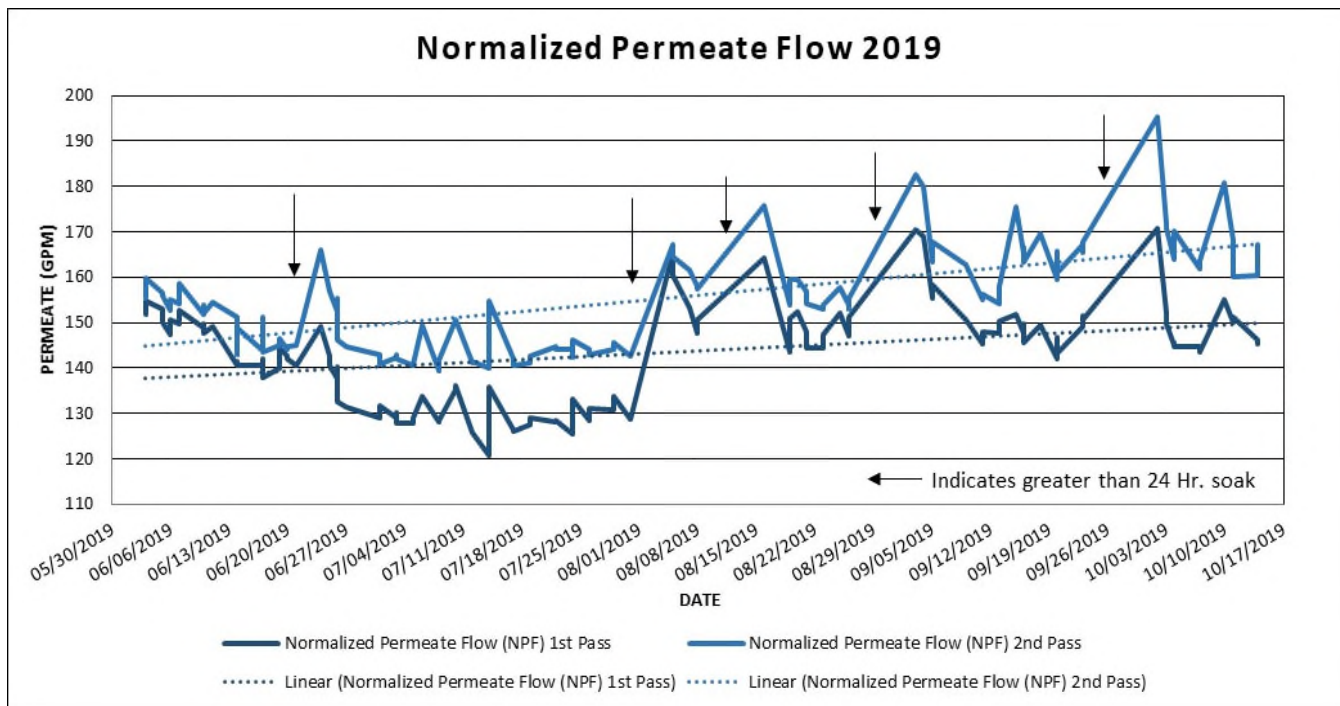
Where

NDP = Net Driving Pressure

NPF = Net Permeate Flow

TCF = Temperature Correction Factor (published values)

NPF measures the amount of permeate water that the RO is producing. A decrease in NPF could indicate that the membranes require cleaning while increases in NPF suggest either improved feed water quality (lower TDS), decreases in membrane foulant, possible leakage of brine seals or other membrane damage. NPF should always be evaluated with other operating parameters and take into account any system adjustments that also contribute to any NPF values. For instance, NPF increases combined with increased permeate conductivity may suggest brine seal leakage or membrane damage. In general, NPF in 1st and 2nd passes declined during the first month of operations, stabilizes during the second month, then increases through the remainder of the season (**Figure 8**). This suggests that during early season operations, fouling may have occurred. The removal of foulant during the mid-season cleaning combined with frequent soak periods associated with system down time resulted in improved system performance but still a slight net decrease in 1st pass membrane performance.



**Figure 8 Beal RO Normalized Permeate Flow**

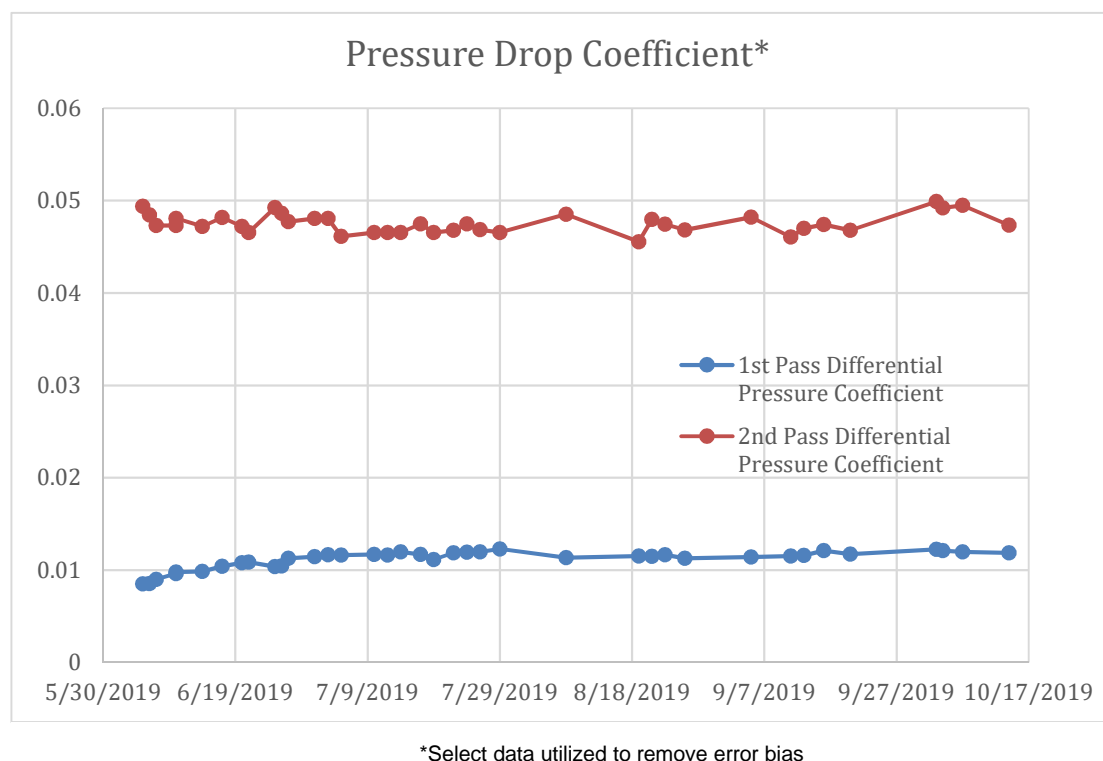
The data presented here is not definitive for several reason. The baseline for this data comparison was chosen as the season startup, which may contain significant bias. Second, the system was designed with a bypass line connecting first pass feed (raw water) and second pass feed (1<sup>st</sup> pass permeate) to help balance feed pressures to each booster pump. However, flows between the bypass line can vary significantly during operation which will alter the “normalization” of the data for second pass. Finally, system adjustments to operating pressures, flows, and permeate production will also impact the “normalization” values. When significant system adjustments were made, plant values were first recorded prior to those adjustments and then after to evaluate the effects of the adjustments on NDP and NPF. Plant field data and the resulting calculated values for NPF are presented in **Appendix B – Tables 1 and 2**.

### Differential Pressure Drop Coefficient

Differential pressure drop, is the difference between feed pressure and concentrate pressure, for a single array or pass. The Differential pressure drop coefficient attempts to normalize differential pressure for changes in flow.

$$\text{Pressure Drop Coefficient} = \frac{(\text{Pass Pressure Drop}(\text{psi}) \equiv [\text{Pass Feed Pressure} - \text{Pass Concentrate Pressure}])}{([\text{Pass Feed Flow}(\text{gpm}) + \text{Pass Concentrate Flow}(\text{gpm})]/2)^{1.5}}$$

In general, increases in the differential pressure drop coefficient are often used as an indicator of obstruction to flow (fouling) within the system. Foulant may be associated with particulates, biological growth, or dissolved solids precipitation (scale). Fluctuations in the coefficient can also be attributed to system adjustments, meter calibrations, feed and concentrate valve functionality, and system stabilization following shutdowns / restarts.



**Figure 9. Calculated Pressure Drop Coefficient**

Increases in the 1<sup>st</sup> pass differential pressure drop coefficient during the first month of operations supports possible membrane fouling followed by more stable performance; however, there were also significant system adjustments that occurred during the first few weeks of operation. The variability of 2<sup>nd</sup> pass coefficient values are likely due to operator adjustments to balance the system which resulted in fluctuations of the 2<sup>nd</sup> pass feed concentrations due to varying amounts of raw water passing through valve YV125A, instrument calibrations (flow meters and transducers), and issues associated with the deteriorating condition of the 2<sup>nd</sup> pass feed valve.

Tetra Tech plans to continue the collection of RO data for the differential pressure drop coefficient calculation during future operations in order to develop better baseline data and refine sampling protocols.

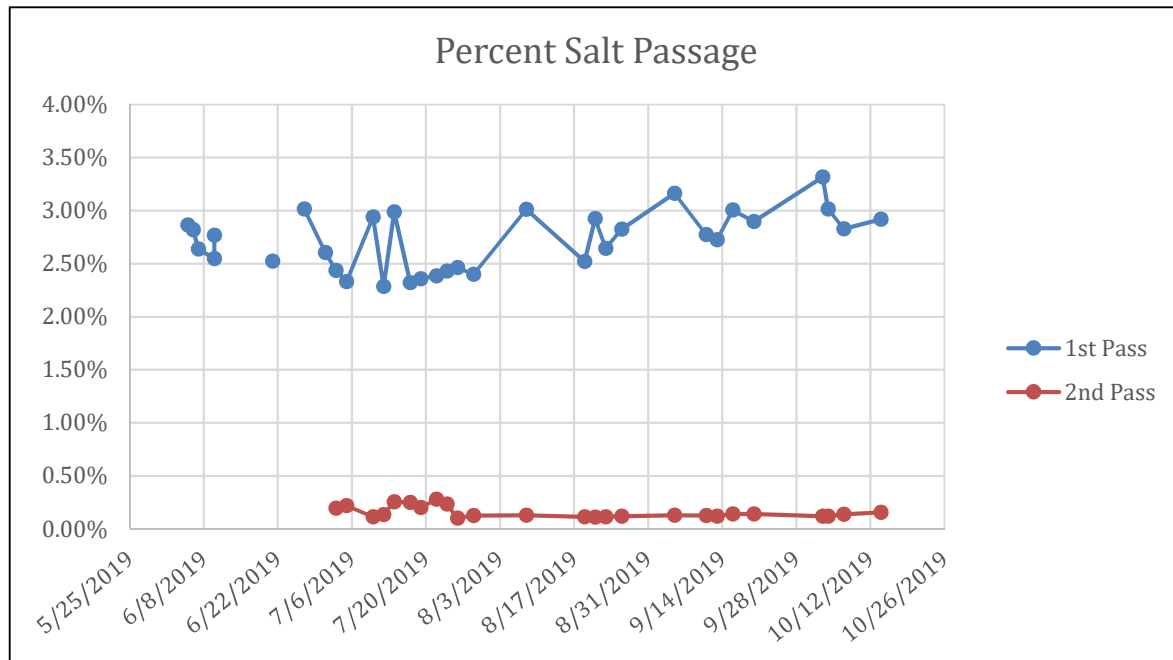
## Percent Salt Passage

Percent salt passage uses feed conductivity, concentrate conductivity, and permeate conductivity to evaluate membrane performance.

$$\% \text{ Salt Passage} = \frac{(\text{Pass Permeate Conductivity (SC)}) \times 2}{(\text{Pass Feed Conductivity (SC)} + \text{Pass Concentrate Conductivity (SC)})}$$

An increase in salt passage may be due to leaking brine seals, fouling, improper pH, high recovery rate, too high or low feed pressures, or changes in feed water chemistry. Initial evaluation of the relevant data collected during 2019 for this metric appears to suggest that 1<sup>st</sup> pass salt passage generally increases ( ) through the season and may suggest either membrane fouling/scaling or excessive operating feed pressure; however, significant system adjustments, instrument calibrations (SC meters), and operational constancy should be recognized as a significant contributor to the data variation. Second pass salt passage appeared to remain relatively stable throughout the season.

Tetra Tech plans to continue the collection of RO data for the percent salt passage calculation during future operations in order to develop better baseline data, evaluate membrane performance, and refine element cleaning protocols.



**Figure 10 Percent Salt Passage**

## Summary of RO Performance

Evaluation of the collective data for the RO during 2019 for net driving pressures, normalized permeate flows, salt passage, and differential pressure drop coefficient suggest the following:

- Mid-season cleaning was effective at removing early season fouling or scaling.
- Frequent extended soak events maybe nearly as effective as cleaning events resulting in minimal or no net fouling or scaling.
- The presence of the YV125A bypass and system adjustments to manage changes in feed chemistry must be considered when evaluating system performance metrics.

## Maintenance Tasks Completed During 2019

The RO system at Beal Mountain has completed its twelfth season of operation. Many of the system components are original equipment installs and due to their age, will have a higher probability for failure, especially when operating under the more strenuous conditions. Major maintenance projects completed in the 2019 operational season are listed below.

### Replacement of Second Pass Membranes

The 2018 Year 11 water treatment statement of work included a line item for the purchase and installation of 35 new second pass membranes. This work was not completed during the 2018 operable season; however, the replacement membranes were purchased under that statement of work. The replacement membranes were installed at the beginning of the 2019 operable season. During installation of the new membranes it was found that the new membranes have a smaller opening on the permeate port such that the membrane to vessel end cap adapter was not compatible. After a short delay, appropriate end cap adapters were obtained and installed without incident.

### Freshwater Pond Investigation

As part of the RO treatment process, permeate water is pumped from the RO Freshwater Storage tank to the freshwater pond located north of the RO building. The pond is utilized to provide the treated water additional exposure to air and sunlight in order to help reduce any residual ammonia (aeration of the water) or cyanide (hydrolyzed in sunlight). At the beginning of the 2018 operating season, a large tear in the Freshwater Ponds PVC liner was observed. Prior to contracting the repair of this liner further evaluation of liner integrity was deemed prudent.

The 2019 Year 12 water treatment statement of work included a line item for dewatering the Freshwater Pond with existing equipment in order to visually inspect the integrity of the synthetic liner. During the period of September and October 2019, the water level in the Freshwater Pond had been drawn down far enough to inspect and sample accessible sediments. Findings were as follows:

- Pond dimensions are approximately 250' x 250' x 50' deep with 1.75:1 slopes.
- The Liner material was compromised in multiple locations and consisted of rips, tears, and separated seams. Compromises were identified on all four pond slopes and at numerous elevations (i.e. above and below the typical water levels in the pond).
- Miscellaneous debris was observed at or near the bottom of the pond which included pipe, pipe fittings, and geotextile fabric.
- Sediment present was highly liquified with low cohesive strength.
- One shallow grab sample of sediment was obtained and submitted for laboratory analysis. Results indicate:
  - Non-detect for RCRA metals
  - Total Cyanide = 6.1 mg/kg
  - Weak acid dissociable cyanide = 0.5 mg/kg
  - Free cyanide =<4 mg/kg
  - Total Extractable Hydrocarbons = 988 mg/kg
    - <31 mg/kg C9-C18 Aliphatics
    - 321 mg/kg C19-C36 Aliphatics
    - 54 mg/kg C11-C22 Aromatics
  - 10.7% organic matter
- Total sediment depth estimated to be three feet but not confirmed. Therefore, sediment volume estimated to be 16,875 cubic feet (582 cubic yards).
- Chemistry of deeper sediments remains unknown.

### Beal RO Room Sump Disposal System

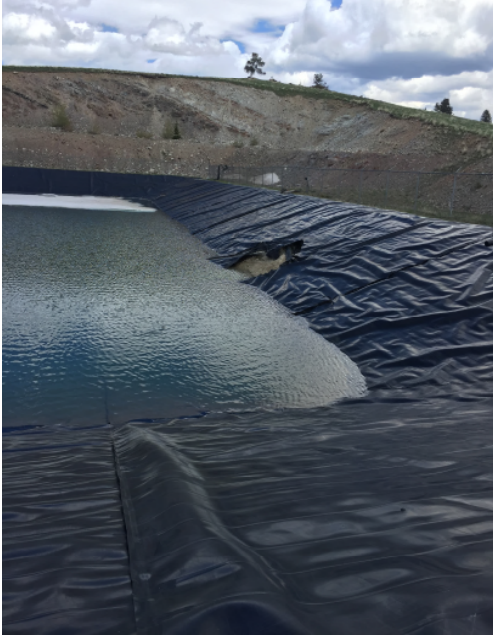


Photo 3. Tear in Freshwater Pond liner spring of 2018.



Photo 4. Freshwater Pond – September 2019.

### First pass reject valve replaced

Tetra Tech personnel purchased a replacement 1<sup>st</sup> pass reject valve and flanges which required custom welding and fabrication in order to fit the location. The original valve had been vibrating excessively during the past operating seasons and had become worn to the point that it is no longer functioning. The valve was fabricated and installed on August 2<sup>nd</sup> while the system is down for the mid-season membrane element cleaning.

### Second Pass feed valve replaced

Tetra Tech personnel purchased and replaced the 2<sup>nd</sup> pass feed valve on October 2<sup>nd</sup>, 2019. The valve, which was original to the system (2008), had become worn over time and began vibrating profusely shortly after startup during 2019 operations. Issues with the valve were most likely exasperated with the replacement of the 2<sup>nd</sup> pass membrane elements and system adjustments implemented to reduce the volume of raw water entering into the 2<sup>nd</sup> pass of the system.

### CIP heaters installed

Two heating elements and their related controls were installed in the CIP system on July 24<sup>th</sup>, 2019. The use of heated water for cleaning solution is recommended by the membrane manufacturers because it can be more effective and efficient at removing fouling. Installation included installing a temporary larger power supply cable to the Connex container and connecting heater controls to safety shutoff switches on the CIP.

### Freshwater Storage Tank pump impeller Replacement

On August 7<sup>th</sup>, the Beal RO unit experienced a system stoppage due to the failure of the impeller in the storage tank pump located immediately north of the Beal building. The pump and motor were removed and upon

inspection, it was discovered that the impeller had completely separated from the motor shaft adaptor. The cause of the damage was not discernable but may have been due to general fatigue as the pump and motor are original to the system (2008) or may have been caused from debris entering the pump from the storage tank as the tanks roof has degraded significantly in the past few years. Tetra Tech installed a temporary replacement pump which is undersized for this operation but continued to work throughout the season. Repair components were procured and installed during demobilization activities and the repaired pump will be installed prior to the 2020 operational season.

## **Exterior Lighting on South and West Building**

Additional LED outdoor lights were added to the exterior of the building during the 2019 operational year. One existing (partially functioning) light was replaced on the south side of the building and two (2) new units were installed on the west side to alleviate health and safety concerns associated with working at the site during dark hours.

## **RO PLC and SCADA Communication**

On August 11<sup>th</sup> at approximately 06:45, a significant electrical surge passed through the Programable Logic Controls (PLC) communications networks at both the RO Water Treatment Plant and at the extraction well located south of the plant. Tetra Tech personnel were notified of the plant shutdown via remote call system and traveled to the site to investigate. Upon arrival at the Beal Mountain site, severe thunderstorm activity was observed in the form of significant lightning, surface water runoff, and hail accumulations exceeding 6-inches. Initially, it was discovered that a pressure transducer located in the permeate water storage tank was not functioning (visible electrical scorching), PLC networks (three total) were not communicating, and the well Variable Frequency Drive (VFD) controller had faulted. Failed component replacement and system trouble shooting continued from August 11<sup>th</sup> through August 16<sup>th</sup> with help from our computer integration subcontractor Industrial System, Inc.

Industrial Systems is based in Vancouver, Washington but was able to remotely access the system to help identify faulty components and direct troubleshooting efforts. As damaged components were identified and replaced, it was discovered that additional components were either intermittently functioning or only partially functioning and needed repair or replacement. Finding replacement components was found to be especially challenging due to the “age” of the Beal RO unit. At 12-years in operation, the hardware platform of the PLC’s, Human Machine Interface (HMI), and communications systems are no longer manufactured or supported. The replacement components were procured through Industrial Systems and were generally remanufactured or factory certified used stock and were located through various vendors and suppliers. Additionally, most of the specialized hardware procured through Industrial Systems required programming that had to be completed through proprietary licensed software at their facility.

The system operated intermittently upon restart on August 16<sup>th</sup> through August 27<sup>th</sup> when the HMI unit stopped working altogether. Upon installation of a remanufactured HMI unit on September 4<sup>th</sup>, the system again ran intermittently through early October as various components were replaced and programming was altered to bypass problematic hardware. From August 12<sup>th</sup> through October 2<sup>nd</sup>, a period consisting of 53 days, the system was either non-operational or partially operational for 24 days and Tetra Tech personnel were onsite 30 days. During this time period, the following components were replaced/installed due to the electrical surge:

- Permeate Tank Pressure Transducer
- Upgraded communications transmitter for internet service
- Well PLC Input Module
- Main PLC Module
- VFD Pump Controller (swapped with onsite spare)
- HMI Unit
- Network Switches, Cables, and Router

- Main PLC Output Module
- Fiber Optic Network Module at Well and Plant
- Main PLC Module (Exchanged for warranty replacement)
- Allen-Bradley Power Supply
- Allen-Bradley Main PLC Chassis

The repair work following the lightning damage was extremely challenging due to the complexity of how the component failures manifested. The exact circumstances of the communication stoppages were rarely repeatable and generally were random. Following a repair, the system would often operate for a period of time (varying from hours to days) without incident but then would unexpectedly fault again. With each repair, it appeared the issues had been resolved, only to have a fault or communications failure cause the RO unit to shut down again. The work that Industrial Systems was conducting over the internet required Tetra Tech personnel to physically be onsite to monitor the system and perform physical tasks and testing needed to troubleshoot the system and complete the repair work.

## **System Maintenance Not Completed in 2019**

The 2019 Year 12 water treatment statement of work included a line item (Subtask 4C) for the replacement of RO system butterfly valves. This work was not completed in 2019 as it was deemed low priority when compared to unexpected costs associated with the August 11, 2019 lightning strike and subsequent communications issues.

## **Recommendations and Discussion**

Tetra Tech is making the following recommendations for future Beal RO water treatment plant operations:

### [Remove or Reconfigure Valve YV125A](#)

Tetra Tech recommends the removal or reprogramming of the “bypass” valve identified as YV125A. The purpose for the valve in the originally designed system was to return a portion of the 1st pass permeate back into 1st pass feed, which reduces influent contaminant concentrations and helps balance feed pressures between 1st and 2nd pass arrays.

Thirteen years of operating the RO system has resulted in higher contaminant concentrations in the leach pad influent. The degrading water quality has reduced the RO system capacity and has resulted in an opposite flow path through the YV125A valve (raw water is now being pushed through the valve into the 2nd pass feed waters). The problem was further exacerbated in 2019 when the 2nd pass membrane elements were replaced and the aging 1st pass elements were not able to supply adequate water to the 2nd pass of the system. This condition will shorten the life of the newly purchased second pass membranes and increase the possibility of a mass precipitation event in the 1st pass of the system, especially if the system is operated at higher production levels.

YV125A valve replacement will require rebuilding significant portions of the 1<sup>st</sup> and 2<sup>nd</sup> pass feed plumbing and will also require a new Variable Frequency Drive (VFD) controller for the 2<sup>nd</sup> pass booster pump. Alterations to the system PLC/SCADA programming will also be necessary. Tetra Tech is currently in the process of identifying the available options and costing where possible.

### [Replace First Pass Membrane Elements](#)

The 1<sup>st</sup> pass consists of 2-stages; stage 1 includes the “A” and “B” Arrays with 4 vessels in each array containing 6 elements per vessel for a total of 48 membrane elements, and stage 2 consists of the “C” Array with 4 vessels containing 6 elements per vessel for a total of 24 membrane elements. In 2009, all 24 of the “C” array membranes were replaced due to significant scaling. In 2012, all 72 of arrays “A”, “B” and “C” membrane elements were replaced due to with severe scaling, and in 2015, 27 membrane elements were replaced in Arrays “A” and “B” in various locations due to significantly higher than average element weights.

Tetra Tech recommends the replacement of all 72 1<sup>st</sup> pass RO membrane elements in order to maximize the production of 2<sup>nd</sup> pass permeate water, reduce the level of solution in the Beal heap leach pad, extend the life of the new (2019) 2<sup>nd</sup> pass membrane elements, and provide a new operational baseline (point of comparison for operational adjustments) reflective of the current raw water conditions.

#### [Replace Media in MMF Vessels 100, 200, and 300](#)

The media material in the Multi Media Filters (MMF's) has not been changed since the construction of the RO system in 2008. The media consists of a gravel layer which covers the underbed plumbing, a 3-inch thick garnet sand layer, a 24-inch thick greensand layer, and a 12-inch thick anthracite layer. Testing of the media in 2016 identified that the greensands are no longer functioning, and that pretreatment media has generally degraded in size which reduces flow capacity, filtering efficiency, and backwash effectiveness through the media.

Tetra Tech RO experts have reviewed laboratory and operational data from the past few operational seasons and have concluded that the greensand media is no longer needed in the MMF configuration due to the Total Iron, Ferrous Iron, and Manganese complexation with cyanides.

Tetra Tech recommends replacing the original media with different products that will provide greater filtering capacity and increased flow capacity. This is especially important because replacement of the 1<sup>st</sup> pass membrane elements and removal of the bypass valve YV125A will necessitate maximum 1<sup>st</sup> pass production which in turn requires achieving the original design raw water feed flow through the MMF's.

#### [Replace RO SCADA Computer and Upgrade Software](#)

Tetra Tech recommends the replacement of the SCADA computer and associated system software. The current computer uses Microsoft Windows 7. During 2019, Microsoft reduced support for Windows 7 and will completely discontinue support in June of 2020. The Microsoft action has led other windows-based software manufactures, such as the WonderWare used by the SCADA program and the Rockwell software utilized by the Human Machine Interface (HMI), to stop support of their software versions for the Windows 7 operating system as well. In addition, the Beal RO SCADA computer has operated in extremely challenging conditions including dirty/dusty air, high humidity, and several plumbing failure events which resulted in complete saturation of the machine. These conditions have resulted in unstable computer operations and increased potential for cyber-attack.

#### [Mid and End of Season Cleanings](#)

Routine RO membrane maintenance is required to optimize the life span of membrane elements, deliver efficient RO operation, and minimize system pressures which will prolong the life of other system components such as pumps and valves. Membrane maintenance includes the practice of "soaking" elements, permeate rinses with CIP, and chemical cleaning. Historically, the Beal RO elements received an end-of-year cleaning and occasionally, when production rates were high, a mid-season cleaning as well. Due to the concentration of contaminants in the solution being treated at the Beal RO water treatment plant, Tetra Tech strongly recommends membrane elements undergo periodic permeate soak events along with a mid and post season cleaning. The midseason cleaning will be utilized to remove accumulated foulants which will maximize membrane life, membrane operational efficiencies, and reduce operational pressures. Every RO system is different and faces a unique cocktail of constituents to remove during the cleaning process, making an exact protocol for chemical usage and cleaning procedure impossible to generically template. However, Tetra Tech continues to identify and develop procedures which are tailored to the Beal site since the CIP purchase in 2017.

The post season cleaning should include the additional step of membrane preservation by pumping a 1% sodium metabisulfite (by weight) solution through the system which is required for proper storage of the membrane elements.

### *Dedicated CIP Equipment Area*

Tetra Tech recommends the construction of a dedicated area within the existing RO building for operation and storage of the CIP system. This approach would greatly reduce hazards (Slips, Trips, and Falls) created by hoses connecting the CIP (currently in Connex storage container) and the RO system as well as hazards associated with ice formation on walking surfaces during cleaning operations conducted during the latter portions of the season. Additionally, relocation of the CIP system would allow for safe working space when adding chemicals to the CIP system.

### *Remove Permeate Storage Tank Cover and Clean Tank*

2<sup>nd</sup> pass permeate water from the RO system is transferred into a large steel Freshwater Storage tank located just north of the RO building. The tank was originally part of the Beal Mountain Mine operation and was incorporated into the RO operations to provide surge and storage capacity for RO operations including the ability to provide water for membrane flushing and cleaning operations, both of which require extremely clean water (i.e. 2<sup>nd</sup> pass permeate) in order to be efficient and prevent further damage to the membrane elements.

During mine operations, an insulated ceiling was installed on the tank which consisted of placing sheet Styrofoam and oriented strand board (OSB) over openings at the top of the tank. The OSB is now degraded and large pieces have been blown off or fallen into the tank from the roof. The debris in the tank can be problematic because it can block the transfer pump outlet and fouls the permeate water needed during membrane maintenance activities.

Tetra Tech recommends removing the remaining roofing material. Additionally, Tetra Tech recommends accessing the tank interior and pressure washing the lower portions of the tank to remove debris.

### *RO System Butterfly Valve Replacement*

Tetra Tech recommends that butterfly valves in the RO system be replaced prior to the start of the system in 2020. The valves are an important component in the RO system and utilized to divert process waters within the system when in operation as well as isolate portions of the system during various cycles of RO operations. All of these valves are original to the system and have reached the end of their operational expectancy. At least two of the valves were identified as allowing fluid to pass while in the closed position while performing system check valve inspections and replacement activities in 2018.

### *Freshwater Pond Level*

Results of the 2019 investigation identified numerous compromises in the liner material of the Freshwater Pond. Tetra Tech recommends the Upper Pond be kept as low as operationally possible during the 2020 water treatment season to minimize the quantity of water that may be entering the groundwater system in that area.

## REFERENCES

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## APPENDIX A – WATER LABORATORY ANALYSIS

## APPENDIX B – 2019 OPERATIONAL FIELD DATA